Surficial Deposits of the Iliamna Quadrangle, Alaska

By ROBERT L. DETTERMAN and BRUCE L. REED

GEOLOGY OF THE ILIAMNA QUADRANGLE, ALASKA

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ABSTRACT

Surficial deposits, primarily of late Pleistocene and Holocene age, cover about 60 percent of the Iliamna quadrangle, which is in southwestern Alaska. The deposits are thickest in the western part, where bedrock is mostly covered. In the mountainous eastern part the surface is largely bedrock, but unconsolidated surficial materials occur locally. The surficial deposits are primarily the result of glaciation, with subsequent modification by glaciofluvial, lacustrine, and marine processes.

The oldest deposits are correlated with the Mak Hill Glaciation of early Wisconsin age. The glaciers coalesced to form a piedmont lobe that covered much of the quadrangle during the herein newly named Kukaklek Stade. The deposits are found only on hilltops 600–1,000 feet above deposits of the next glaciation in the western part of the quadrangle.

Most of the surficial materials, as well as the present topography of the quadrangle, resulted from four stades of the Brooks Lake Glaciation that are correlated with the late (classical) Wisconsin Glaciation of the conterminous United States. During the two oldest stades, herein named the Kvichak and Iliamna, the glaciers coalesced to form piedmont lobes that covered most of the quadrangle; Iliamna Lake and other large lake basins were formed. The two youngest stades, Newhalen (new) and Iliuk, were minor glacial advances of the alpine valley glacier type. Moraines of the Iliuk Stade locally divide lake basins into two parts.

Two stades of the Alaskan Glaciation, of Holocene age, are recognized in the quadrangle. Glaciers of the Tustumena Stade advanced 1–3 miles from the cirques, and locally three advances can be mapped. During the subsequent Tunnel Stade the ice rarely advanced more than 1 mile beyond the cirque threshold. The small modern glaciers are remnants of the Tunnel Stade.

Iliamna Lake, originally dammed by a moraine of the Kvichak Stade, attained its present size and shape when dammed by a morine of the Iliamna Stade; it formed major terrace levels at above 40, 80, 100, and 130 feet above the present lake level. The highest stand of water was about 150 feet above the present level. Radiocarbon-dated beach deposits indicate that the 80-foot level was formed at least 8,520 years ago. An intermediate 53-foot level was formed about 5,520 years ago.

Elevated marine beach deposits and wave-cut bedrock platforms along the west coast of Cook Inlet indicate that the coast is rising. Radiocarbon-dated material from one locality at Kamishak Bay suggests that the rate of uplift is about 2 feet per century.

INTRODUCTION

The first recorded exploration of the Cook Inlet area was by Capt. James Cook in June 1778. Capt. Nathaniel Portlock and Capt. George Dixon visited the area in 1786, and Capt. George Vancouver in 1794. A Spanish expedition under Lt. Ignacio Artega and Don Francisco Maurelle came in 1779. The Russians were also early visitors in the area. Peter Doroshin and Capt. Archimandritov mapped parts of Cook Inlet in 1848–53; they were the first to note, in 1853, the oil seepages on what is now the Iniskin Peninsula. Russian missionaries were active, also, during the 1800's and the Russian Orthodox faith is still the major religion of the native population.

Part of the Iliamna quadrangle was prospected for gold, silver, copper, and petroleum during the period from 1893 to 1910. Many claims and leases were issued, but all proved to be uneconomical and most activity had stopped by 1915. Mapping by the Geological Survey and exploration by private industry have renewed interest in the area. Several iron ore occurrences were staked in 1964. The main potential for the area, however, lies in its recreation possibilities.

LOCATION AND ACCESSIBILITY

The area described in this report comprises the Iliamna quadrangle (1:250,000) at the base of the Alaska Peninsulan (fig. 1); it contains 7,310 square miles, of which about 2,650 square miles is covered by the water of Cook Inlet, Iliamna Lake, and other large lakes. Anchorage is about 125 miles northeast of the quadrangle, Homer about 50 miles east, and King Salmon about 50 miles southwest. A few square miles along the southeast edge of the quadrangle is included in the Katmai National Monument. The Valley of Ten Thousand Smokes is 50 miles to the south.

Iliamna Lake occupies the central part of the quadrangle; it is 80 miles long and averages about 12 miles wide. This is the second largest natural fresh-water lake entirely within the confines of the United States; it has 1,033 square miles of surface area, 260 miles of shoreline, and is as much as 1,192 feet deep. Other nearby large lakes include Kukaklek, Nonvianuk, Battle, Gibraltar, Kakhonak, Lower Tazimina, and Sixmile. In addition, there are many smaller lakes and myriad glacial ponds from a few hundreds of feet to several miles in length.

The quadrangle is readily accessible by both air and water transportation. A scheduled airline makes regular stops at Iliamna, and there are seven landing strips for light wheeled planes. Small float planes can land on many of the numerous small

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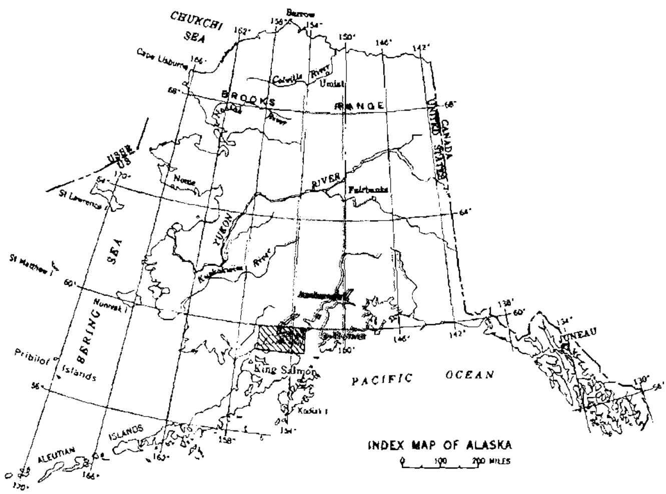

FIGURE 1.—Index map showing location of the Iliamna quadrangle.

lakes, ponds, and rivers throughout the area. Fishing boats visit many of the bays along Cook Inlet, but there is no scheduled water transportation service at present. A dock, on the west side of Cook Inlet, for the Alaska State ferry system and a road across the quadrangle to King Salmon are under consideration. Fishing boats make the trip from Iliamna Lake to Bristol Bay by way of the Kvichak River.

There are two usable gravel roads in the quadrangle; both are used mainly for the movement of supplies between Cook Inlet and the inland villages. The road between Pile Bay Village and Williamsport is part of the State highway system; it is open and maintained between late May and early October. The other road goes from Iliamna to Nondalton on Sixmile Lake; only the first 3 miles between Iliamna and the Iliamna airport is maintained. A road on Iniskin Peninsula is no longer usable.

PREVIOUS INVESTIGATIONS

Part of the Iliamna quadrangle had been mapped prior to the present investigation, but about half of the area had never been studied. The surficial deposits, in particular, had received only slight attention from early investigators. The first known report was by Martin (1905), who visited Oil Bay in 1903, while drilling for petroleum was in progress. The following year Stanton and Martin (1905) returned and measured some of the many well-exposed sections of Jurassic sedimentary rocks exposed at Iniskin, Oil, and Chinitna Bays. The report of the 1909 survey by Martin and Katz (1912) contains the most complete and detailed account of the Iliamna region prior to the present investigation. Their map covers the northeast third of the quadrangle and includes all the areas in which claims or leases for gold, silver, copper, or petroleum had been issued; this report supplemented the rather brief account of the survey published earlier by Martin and Katz (1909).

Insofar as is known, there were no investigations in the area between 1909 and 1921, when Moffit (1922, 1927), A. A. Baker, and Gerald Fitzgerald mapped the Iniskin Peninsula and adjoining areas to the north. Shortly after their work, Mather (1923), accompanied by R. H. Sargent, mapped a small area near Kamishak Bay.

The Iniskin Peninsula was mapped in considerable detail starting with the work of Kellum (1945) and Helmuth Wedow, Jr., in 1944, and continuing with Kirschner and Minard (1949), Imlay (1953, 1959, 1961, 1962a, b, 1964), Don J. Miller, Hartsock (1954), Arthur Grantz, and Juhle (1955). The work on Iniskin

Peninsula and the area to the north was completed in 1958 by Robert L. Detterman (1963), and the final report was prepared by Detterman and Hartsock (1966).

Between 1944 and 1958 most of the effort by the U.S. Geological Survey was concentrated in the coastal region north of Iniskin Bay, where there are many fine exposures of marine Jurassic rocks. However, a few small field parties concerned mainly with specific mineral resources were working in the Iliamna quadrangle. One of the areas investigated was the pumice deposit on Augustine Island (Moxham, 1951). At about the same time Moxham and Nelson (1952) did a trace-element study along the shoreline of Iliamna Lake, and the U.S. Bureau of Mines did some work on the Millett cooper prospect on the north side of Iliamna Lake (Rutledge and Mulligan, 1952). Muller and Coulter (1953) did a brief survey of the Iliamna road for the Department of the Army in September 1953.

PRESENT INVESTIGATIONS

The investigations that led to this report were an outgrowth of the detailed studies made on Iniskin Peninsula and adjacent area to the north. The fieldwork started in 1961 when R. L. Detterman and Roger A. Hope studied the coastal mountain area between Iniskin Bay and Amakdedori and including Augustine Island. B. L. Reed joined the project in 1962; Reed and Douglas McDowell mapped part of the Iliamna Lake shoreline as well as the shorelines and adjacent areas of Kakhonak, Gibraltar, and Battle Lakes during that summer by skiff. Most of the mapping in the quadrangle was done between 1963 and 1967 by Detterman and Reed using a combination of small float-equipped airplane, helicopter, and skiff; they were assisted by C. E. Bickel in 1963 and 1964, Travis Hudson in 1965 and 1966, and John Erfurth in 1967.

Results of some of the topical studies conducted during the investigation have been published, as well as some preliminary maps. The topical studies include age dating by both radiocarbon and potassium-argon methods (Detterman, Reed, and Rubin, 1965; Detterman, Reed, and Lanphere, 1965; and Reed and Lanphere, 1969) as well as spectrographic analysis of stream sediment and mineralized bedrock samples (Detterman and Reed, 1965; Reed and Detterman, 1965, 1966; and Reed, 1967). Several preliminary maps have been published (Detterman and Reed, 1964, 1967, 1968). A short account of the volcanic activity on Augustine Island was prepared by Detterman (1968). The State of Alaska conducted a survey of the Paint River area in 1963 (Richter and Herreid, 1965).

Contacts between the surficial deposits shown on plate 1 were mapped chiefly from aerial photographs, supplemented by field observations.

ACKNOWLEDGMENTS

Fieldwork in the Iliamna quadrangle was greatly facilitated by the cooperation and help, both technical and nontechnical, of many individuals; it is impossible to acknowledge all of them, but some of the major contributors must be recognized. Chief among these are Mr. and Mrs. Carl Williams and Mr. and Mrs. Richard Williams of Pile Bay Village and Homer, Alaska, who helped with the logistic support of the project. We are deeply indebted, also, to Mr. and Mrs. Robert Walker of Iliamna, and Mr. and Mrs. Oren Hudson of Iliamna and Anchorage.

Many individuals within the Geological Survey gave technical assistance on some of the more specialized aspects of the program. Chief among these were Marvin A. Lanphere and Meyer Rubin on the radiometric age dating of rock and carbon-14 samples, and Ralph Imlay and David Jones on identifying the many paleontologic specimens.

We also express our appreciation to the many geologists of the oil and mining companies who were working in the area at the same time. The exchange of ideas helped to solve many of the more perplexing geologic problems. We are also indebted to the personnel of Fisheries Research Institute of the University of Washington, who maintain a laboratory on Porcupine Island, for furnishing data on the bathymetry of Iliamna Lake.

GEOGRAPHY

PHYSIOGRAPHY

The topography of the quadrangle is extremely varied. Four major physiographic divisions are represented (Wahrhaftig, 1965): the Alaska Range (southern part), Aleutian Range, Nushagak-Bristol Bay Lowlands, and Nushagak-Big River Hills (fig. 2).

Alaska Range.—Rugged precipitous mountains, deep glacially scarred valleys, and abundant bays along the coast characterize the southern part of the Alaska Range in the quadrangle. This section contains the highest mountain, North Twin (7,702 ft), and has local relief of 2,000–5,000 feet. The peaks are commonly horns that are separated by arêtes which are locally worn down to form cols. Most of the fiordlike bays have cols at their heads which lead into the interior. The valleys are for the most part broad, U-shaped, and have truncated spurs and many waterfalls from hanging tributaries.

The mountains rise abruptly 2,000–3,000 feet above Cook Inlet without bordering coastal plains, and they form a climatic barrier between the sea coast and the interior. Numerous small glaciers are present in this part of the quadrangle, and the area was heavily glaciated during the Pleistocene Epoch.

Aleutian Range.—The Aleutian Range in many respects is similar to the Alaska Range but is less rugged. The mountains are more rounded and lower, local relief of 1,000–3,000 feet, and generally lack the deep U-shaped valleys characteristic of the Alaska Range. The division between these two great mountain ranges was made at the only logical spot by Wahrhaftig (1965); the Bruin Bay pass is the only major break in the chain between Anchorage and the Port Moller area, near the end of the Alaska Peninsula, a distance of over 600 miles.

The mountains, for the most part, are several miles inland from the coast and rise gently above the surrounding lowlands. Valleys are broad and open, and most are choked with glacial debris. This part of the quadrangle was heavily glaciated also, but much of the debris still remains in the valleys, in contrast to the Alaska Range, where most of the glacial drift was carried out of the mountains by the glaciers and subsequent glaciofluvial action.

Nushagak-Bristol Bay Lowlands.—The area around the west end of Iliamna Lake is in the Nushagak-Bristol Bay Lowlands. This is a monotonous nearly level plain that slopes gently southwest toward Bristol Bay. It contains abundant swamps and lakes and has a few hundred feet of maximum relief. The area is almost entirely underlain by surficial materials with only a few bedrock hills southwest of Kukaklek Lake. These low rounded hills are the highest topographic features in this part of the quadrangle; the highest point is 1,372 feet.

Nushagak-Big River Hills.—The northwestern part of the quadrangle falls into the Nushagak-Big River Hills physiographic division. This is an area of low rolling hills separated by wide shallow valleys choked with abundant glacial debris. Locally the relief is as much as 2,000 feet near Groundhog Mountain, but for the most part is between 500 and 1,500 feet. Most of the area is an upland surface that stands 600–1,000 feet above the lowlands around Iliamna Lake. This upland is formed mainly of glacial debris from the Alaska Range to the northeast. Low rounded hills, mainly of Tertiary volcanic rock, rise above this surface.

CLIMATE

Several well-defined climatic zones are formed in the quadrangle, primarily by the orographic effect of the coastal mountains

FIGURE 2.—Physiographic divisions (modified from Wahrhaftig, 1965) and vegetation zones (modified from Siagfoos, 1958) of the Iliamna quadrangle. Zone: 1. Heavily forested (mixed spruce and deciduous) with brush. 2. Forested (spruce or deciduous), moderate to light brush. 3. Spruce forest, light to moderate brush. 4. Light brush with occasional stand of spruce or deciduous trees. 5. Dense brush, few trees. 6. Barren ground, tundra with occasional clumps of brush; includes areas above tree line.

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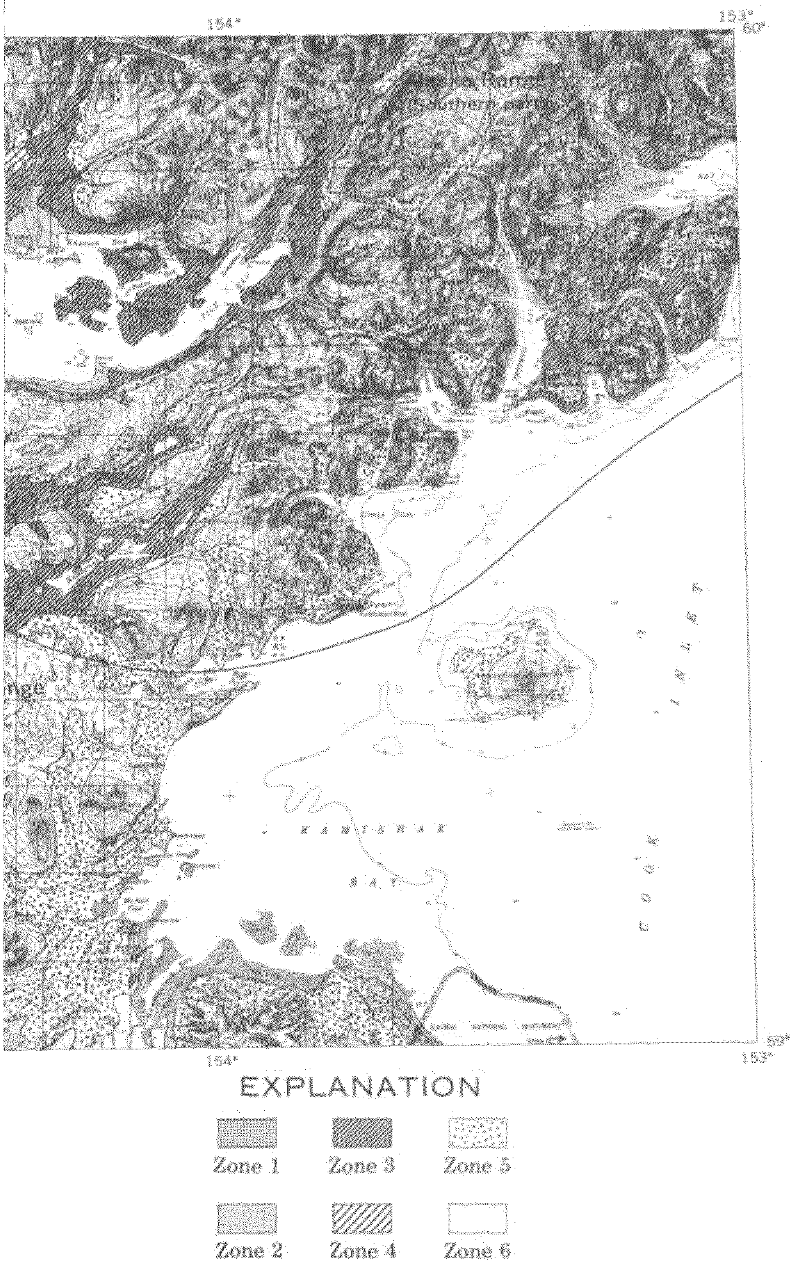

FIGURE 2.—Continued.

(Mitchell, 1958) which give the area bordering Cook Inlet a subpolar marine climate characterized by abundant rain and fog with mild temperature (fig. 3). West of the mountains the dry cold continental-type climate of interior Alaska is more in evidence, except in the southwestern part of the quadrangle where storms coming in from the Aleutian Islands modify the weather still further.

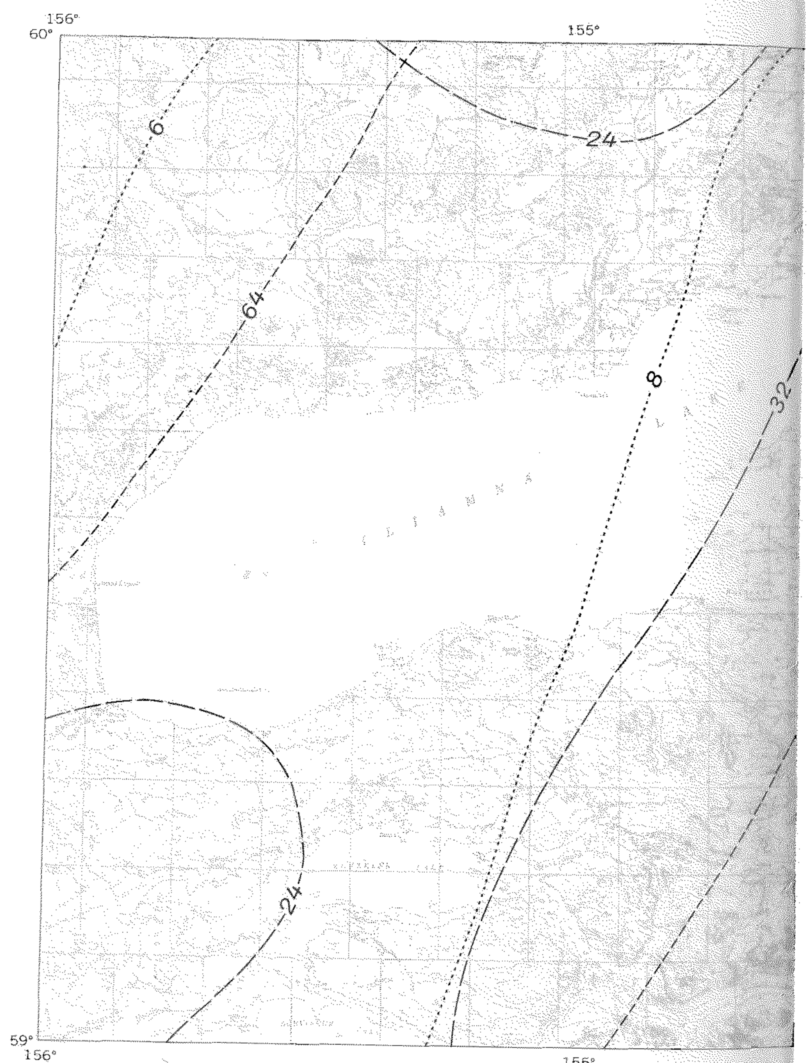

FIGURE 3.—Precipitation, temperature, glaciers, and permafrost zones of the Iliamna quadrangle, Alaska. Long-dashed line is isohyet, line of equal precipitation, in inches (from Watson, 1959, and Wahrhaftig, 1965). Short-dashed line is isotherm, mean daily maximum temperature, in degrees Fahrenheit, for July (from Watson, 1959). Dotted line, isotherm, mean daily minimum temperature for January (from Watson, 1959). Shading shows existing glaciers. Permafrost zone boundary from Hopkins, Karlstrom, and others, (1955, fig. 11).

Rainfall in summer and snowfall in winter are extremely heavy in the northeastern part of the quadrangle (fig. 3). This is at least in part due to the cooling effect of the glaciers around Iliamna Volcano on the moisture-laden air coming up Cook Inlet.

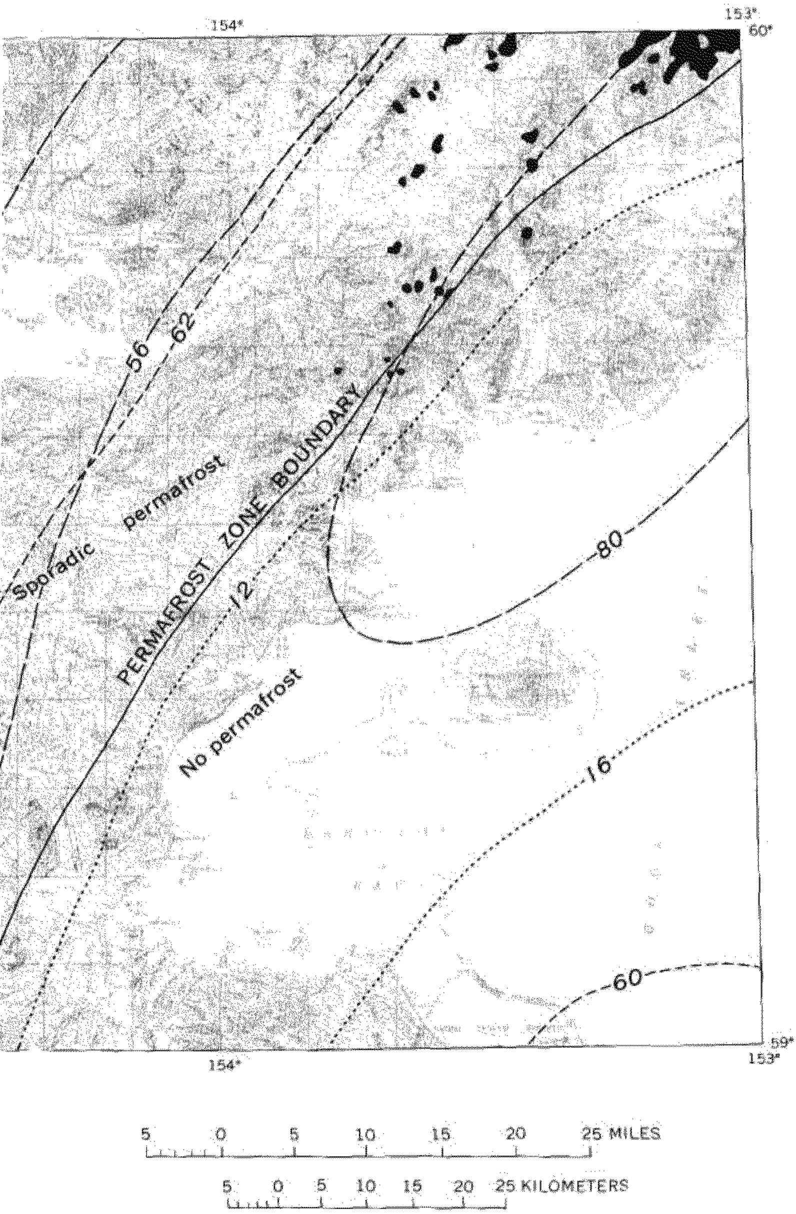

FIGURE 3.—Continued.

West of the coastal mountains the amount of precipitation decreases rapidly to less than half of that received along Cook Inlet. The temperature inland is correspondingly warmer in summer and colder in winter than along the coast, where the almost constant cloud cover exerts a modifying influence. Low barometric pressure centers with accompanying storms from the Aleutian Islands sweep up Bristol Bay and across the area of the quadrangle from early July through December. During the early part of the year the quadrangle is more under the influence of the cold dry air associated with high pressure areas coming in from the north.

Modern glaciers are confined to the high precipitation area in the northeastern part of the quadrangle. Most are small except for those coming from Iliamna Volcano, just off the northeastern corner of the map, and most are stagnant. Except for those on Iliamna Volcano, all the glaciers are on northwest-facing peaks and have an indicated firn line of about 3,500 feet.

VEGETATION

In response to the many climatic factors, vegetation within the quadrangle is highly variable. Six vegetational zones can be mapped (fig. 2), ranging from rain forest typical of the southeastern coast of Alaska to tundra-covered areas like those of the far north.

Zone 1, found only in the northeastern part near Chinitna, Iniskin, and Iliamna Bays, is heavily forested with a mixture of Sitka spruce (*Picea sitchensis*) and black cottonwood (*Populus trichocarpa*) forming the upper story and a dense undergrowth of red alder (*Alnus rubra*) and willow (*Salix* sp.) below. Balsam poplar (*Populus balsamifera*) is found locally. Devilsclub (*Oplopanax horridus*) is ubiquitous amongst the brush cover as are ferns; fire weed (*Epilobium angustifolium*) and numerous grasses grow in open areas within the brush cover.

Zone 2 is found locally throughout all but the extreme northeastern part of the quadrangle; it is similar to zone 1, but the spruce is mainly white (*Picea glauca*) or mixed with black (*P. mariana*) and there are a few aspen (*Populus tremuloides*) and birch (*Betula papyrifera*) mixed with the balsam poplar. The forest and brush cover is less dense than in zone 1 partly owing to the decrease in rainfall.

The spruce forest of zone 3 forms well-defined areas throughout the quadrangle wherever favorable climatic conditions exist. Hopkins (1959) demonstrated that the spruce forest in Alaska is limited to areas having at least 130 "degree days" per year when the temperature reaches or exceeds 50° F. The spruce forest is mainly a mixture of white and black spruce, although pure stands of both types are found locally. The white spruce prefers well-drained sites on hillsides and on gravel terraces along streams, whereas the black spruce is on poorly drained sites underlain by thick peat layers and fine-grained soils, which is typical of the taiga of interior Alaska. The spruce forest is more open than the mixed forest, and dwarf birch (*Betula nana*) along with alder and willow form the major elements of the undergrowth.

Areas where trees and brush are just starting to grow are mapped as zone 4. The trees are mainly spruce, but include occasional cottonwood and willow along some of the streams. The willows are commonly almost of tree size, 4–6 inches in diameter and 30 feet tall.

In zone 5 alder (*Alnus* spp.) is the main element of the dense brush unit which reaches its greatest development in coastal areas, where it forms a solid mat from sea level to about 1,000–1,200 feet. Willow is commonly found along streams in this zone, but the steep mountainsides are almost exclusively covered with alder.

The barren ground, mapped as zone 6, is actually a combination of several plant communities, as well as bare rock surfaces. Tundra plant communities, mixtures of shrub and herbaceous plants, occupy most of the western part of the quadrangle above timberline. The shrubs are mainly dwarf birch and heath (*Erica* spp.), and the herbaceous plants include sedge (*Carex aquatilis*) and cotton grass (*Eriophorum* sp.) tussocks. Willow and alder are also components of the shrub community, which is confined to the better drained areas of the tundra region. Poorly drained regions underlain by fine soils support only the herbaceous plants and grasses. Strandline plants, mainly salt grass, are found along the shore of Cook Inlet. Lichen and moss form the main cover for the higher mountains.

The Iliamna quadrangle was extensively glaciated during the Pleistocene, and all areas below present timberline, 800–1,200 feet, were covered by ice. Consequently, the forests are still in the process of reestablishing themselves in the area. A comparison of figure 2 (this report) with plate 4 of Martin and Katz (1912, p. 16) will show that the forested areas have increased in size and that the tree line has migrated considerably to the west during the past 50–60 years. There have been very minor changes in the forested areas along Cook Inlet in the same period; this may be due in part to the dense brush cover choking out tree seedlings. Cottonwood is the first of the trees to be established in areas of heavy brush, and it has invaded Iliamna Bay and Cottonwood Bay as well as a few small areas along the Kamishak and Douglas

Rivers. Probably the main reason for the more rapid expansion of the forests to the west is that during the period from May to September, when the trees drop their seeds, the dominant wind direction is from the southeast. This is the only acceptable explanation, as there is practically no difference in temperature, precipitation, or soil conditions between adjoining forested and unforested areas.

Numerous small flowering plants, berries, ferns, and grasses compose the ground cover throughout the area. The greatest profusion of the smaller plants occurs west of the coastal mountains, including the tundra areas which are covered by caribou lichen (*Cladonia rangiferina*). No attempt was made to identify the smaller plants systematically, but the list probably would include several hundred species.

SOILS

Soil formation and development largely dates from the close of the Wisconsin Glaciation, when glaciers covered most of the quadrangle. The soils were not specifically investigated during the fieldwork, but some profiles were obtained when test pits were dug to gather material for carbon-14 analysis. These pits were largely confined to beach ridges and terraces along Iliamna Lake and to marine terraces along Cook Inlet; therefore, the soil profiles may not be applicable to the entire quadrangle.

The profiles investigated were all podzol soils, and all show one or more interruptions by marine or lacustrine transgression with subsequent development of new soil profiles. One of the more complete profiles was exposed in a sea cliff 4 miles northeast of the mouth of Bruin Bay. The section was as follows:

Podzol.

- A_0, 6 inches dark-brown loam, somewhat fibrous; contains many roots; overlain by ½-inch white volcanic ash layer.
- A_1, 1-inch black organic humus layer.
- A_2, 11 inches light-yellowish-brown sandy loam; some root fragments.
- B_2, 6 inches light-brown sandy loam; numerous weakly cemented fragments.
- B_3, 20 inches light-tan to yellowish-gray silty sand to sandy loam, friable.
- C, 30+ inches yellow coarse beach sand.

This soil profile overlay a much condensed profile resting on about 60 feet of sand and gravel of an old beach deposit.

The white volcanic ash layer overlying the A_0 horizon is a feature common to all areas investigated; it is from the 1912 eruption in the Mount Katmi area and ranges in thickness from about 4 inches in the Kamishak Bay area to less than one-fourth inch in the northwestern part of the quadrangle.

PERMAFROST

Permafrost or perennially frozen ground is present at a few localities in the Iliamna quadrangle. Most, if not all, is a relict of former periods of glaciation when the temperature was lower. The quadrangle falls primarily in the zone of sporadic permafrost (fig. 3), as defined by Hopkins, Karlstrom, and others (1955). The coastal region is in the permafrost-free zone.

In the sporadic permafrost zone, perennially frozen ground is most likely to be found in areas underlain by fine-grained sediments, particularly if they have a high organic content or are covered by a thick mat of peat and moss. Permafrost is most likely to be found in the loess-covered deposits of the Mak Hill Glaciation, the proglacial lake deposits at the west end of Iliamna Lake, and the fine-grained outwash deposits near the outer edge of outwash plains.

The presence of tundra vegetation is not necessarily a criterion for permafrost in the quadrangle, but a cover of sphagnum mosses, sedge, and cottongrass may indicate the presence of frozen ground, as these plants grow mainly in poorly drained swampy areas. Thin lenticular masses of ice are present in the forested areas bordering Kakhonak and Meadow Lakes and are probably present elsewhere in forested areas; these may be relict masses protected by a thick layer of moss.

An average mean temperature of less than 32° F is required for the formation of permafrost. The temperature within the quadrangle is highly variable, but from the few weather records available a mean temperature of 35°–36° F is indicated. This is marginal to the preservation of permafrost, although isolated microclimates may exist where it can form under present conditions or at least maintain previously formed features.

Relict permafrost features are most common in the northwestern part of the quadrangle along Kaskanak Creek and the Stuyahok and Koktuli Rivers. This part of the area is subjected to cold continental-type airmasses with low winter temperatures (fig. 3). Remnants of both high- and low-center ice-wedge polygons are found along the Stuyahok River (fig. 4), and a few frost-crack polygons form on the glaciofluvial deposits. Frost-crack polygons generally form in coarse materials and do not necessarily indicate permafrost at depth. The Stuyahok River still retains many characteristics of a stream in perennially frozen ground, such as sharply angular changes in direction owing to melting along edges of polygons, and numerous small pools that are relict beaded drainage formed at intersections of polygons. Several of the lakes in the swampy areas show the characteristic serrated

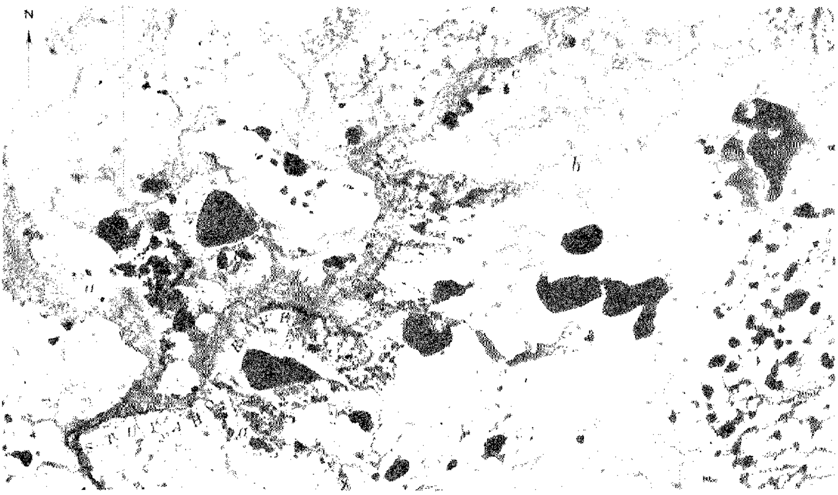

FIGURE 4.—Permafrost features along Stuyahok River. *a*, Polygonal ground, mainly low-center polygons. *b*, Frost-crack polygons and traces of high-center polygons on pitted outwash. *c*, Angular drainage channels and relict beaded streams. *d*, Serrated lake bank indicating possible thermokarst development. Photograph by U.S. Air Force, 1955. Location of area shown on plate 1.

banks of thermokarst lakes, and oxbows formed by cutoff meanders are locally enlarged by melting.

SETTLEMENTS AND POPULATION

The quadrangle has a population of about 500, nearly all of whom live in or near seven small villages. Nondalton on Sixmile Lake is the largest settlement. The others are Iliamna, Newhalen, Pedro Bay, and Pile Bay on the north shore of Iliamna Lake; Kakhonak on the south shore; and Igiugig at the outlet of Iliamna Lake. Most of the quadrangle, including all of the Cook Inlet coastline, is uninhabited.

The population, about 75 percent native, belongs to two major linguistic groups. One, Kialagmiut Eskimo, comprises Newhalen, Igiugig, and Kakhonak; the other, Tanaina Indian, a subgroup of the Athapascan, comprises Nondalton and Pedro Bay (Wunnicke and others, 1968). A few Aleuts and the white population are scattered throughout the villages. Historic village sites include Kaskanak, Nogeling, Chekok, and Kakhonak on Iliamna Lake, Ashivak and Amakdedori on Kamishak Bay, and old Iliamna on the Iliamna River.

SUMMARY OF BEDROCK GEOLOGY

As the bedrock geology of the Iliamna quadrangle will be the subject of another report, the various bedrock units will only be briefly mentioned here. A map showing bedrock geology has been open filed (Detterman and Reed, 1968).

Areas of bedrock are mainly confined to the mountainous eastern part of the quadrangle. Unconsolidated surficial materials mantle most of the western part, but bedrock is exposed on some of the higher hills. In many places the surficial mantle is thin and the bedrock can be assumed, but for the purpose of the geologic map (pl. 1) these areas are shown as surficial deposits.

The oldest rocks exposed belong to an unnamed metamorphic unit of Permian and (or) Triassic age. These rocks occur as small roof pendants composed of amphibolite, quartz-mica schist, garnet schist, chlorite schist, quartzite, phyllite, and marble within the intrusive complex that forms the core of the Chigmit Mountains. A migmatite zone is present locally between the metamorphic and intrusive rocks. The intrusive rocks are granitic and dioritic and were emplaced during the Early and Middle Jurassic, Late Cretaceous, and middle Tertiary (Reed and Lanphere, 1969).

Late Triassic sedimentary and extrusive rocks and Early Jurassic extrusive rocks are found on both the east and west flanks of the mountains. An unnamed greenstone unit, an unnamed white to light-gray limestone, and the dark-gray limestone, varicolored chert, and shale of the Kamishak Formation make up the Late Triassic rocks. The Early Jurassic rocks are mainly flows, volcanic breccias, agglomerates, and tuffs of the Talkeetna Formation.

Rocks along most of the Cook Inlet shoreline consist of gently dipping graywacke, sandstone, conglomerate, siltstone, arkose, and shale of Middle and Late Jurassic age. All marine and abundantly fossiliferous, they comprise the Tuxedni Group and the Chinitna and Naknek Formations. They are separated from the older, more highly deformed Mesozoic rocks by the Bruin Bay fault—a major high-angle reverse fault on the Alaska Peninsula. Four small outcrops of sandstone and shale of the Late Cretaceous Kaguyak Formation are present along the south edge of the area near Kamishak Bay.

Tertiary extrusive rocks are exposed in scattered outcrops throughout the western part of the quadrangle. These are mainly flows, breccias, tuffs and welded tuffs of andesitic to basaltic composition. In a few small areas, Tertiary conglomerate, sandstone, and shale are interbedded with the volcanic sequence.

Pleistocene and Holocene volcanic rocks form Augustine Island, and a few small flows of similar age that issued from Iliamna Volcano are present in the northeast corner of the quadrangle.

PLEISTOCENE GLACIAL DEPOSITS

Deposits formed by Pleistocene glacial action are far more extensive than those formed during the Holocene, when glaciers were confined to the higher mountains in the eastern part of the quadrangle. Most of the deposits were formed by four major Pleistocene advances that can be correlated by position, morphology, radiocarbon dating, and topographic expression with four advances of the late (classical) Wisconsin Glaciation that have been mapped elsewhere in Alaska. The sequence of (classical) Wisconsin deposits in the quadrangle is exceptionally complete and provides an excellent tie between those around Naknek Lake (Muller, 1953) and those on the east side of Cook Inlet (Karlstrom, 1953, 1957, 1960, 1964). This period of glacial activity is termed the "Brooks Lake Glaciation" (Muller, 1953; Detterman, Reed, and Rubin, 1965). The individual stades are named to facilitate their discussion; they are, from oldest to youngest: Kvichak, Iliamna, Newhalen, and Iliuk.

Glacial deposits older than those of the Brooks Lake Glaciation are found on hilltops at several localities in the western part of the quadrangle. The general character and position of these deposits suggest that although somewhat older than the Brooks Lake they are probably still part of the Wisconsin Stage. Their exact age has not been determined, but we consider them to be equivalent to the Mak Hill Glaciation (Muller, 1953), which we believe to be of early Wisconsin age.

MAK HILL GLACIATION, KUKAKLEK STADE

Drift of the Mak Hill Glaciation is best preserved on upland surfaces and hilltops west of Kukaklek Lake. All the deposits appear to have been deposited by one advance, here called the Kukaklek State after the lake. The type locality is designated the morainal hills 8 miles west of the outlet of the lake.

The group of hills along the west side of the quadrangle between the Koktuli River and Kaskanak Creek also contains some fairly well preserved deposits of this advance. At both localities the drift is 200–600 feet higher than, and several miles in front of, the nearest Brooks Lake moraine. Several other deposits of poorly preserved drift are mapped as part of this advance. Most are in the Koktuli River valley and between Kukaklek and Nonvianuk Lakes, and a small one lies just south of the west end of Iliamna Lake. All lie above or beyond the margin of the well-defined first advance of the Brooks Lake Glaciation.

Morainal deposits.—Moraines of the Kukaklek Stade are considerably modified and subdued, but locally the lobate end moraine can still be identified. Morainal ridges are not as sharp and distinct as those of the Brooks Lake Glaciation, but have, instead, a characteristic flat-topped appearance (fig. 5) due in part to mass wasting and in part to a thin loess cover. Kettle basins are mainly drained or filled with sediment and vegetation; the deeper ones still contain water, but scarps cut into the bordering moraine show that they were once much larger. Surface drainage is moderately well integrated, but all stream valleys now contain sluggish meandering underfit streams, and in general the morainal areas are swampy and poorly drained. The drift contains much silt- and clay-size material.

Terraced and modified morainal deposits.—Modified morainal deposits of the Kukaklek Stade generally lie several miles behind the morainal front; most occur south of Kukaklek Lake and along the Koktuli River. Most were probably deposited as ground moraine, as they are behind the morainal front and ground moraine topography can be identified locally. The deposits were modified primarily by running water during the melting of the Kvichak Stade of the Brooks Lake Glaciation. The topography was further subdued by loess deposition at the same time. Abundant silt was available in the braided stream channels during winter months and was deposited as loess whenever the wind blew. The result

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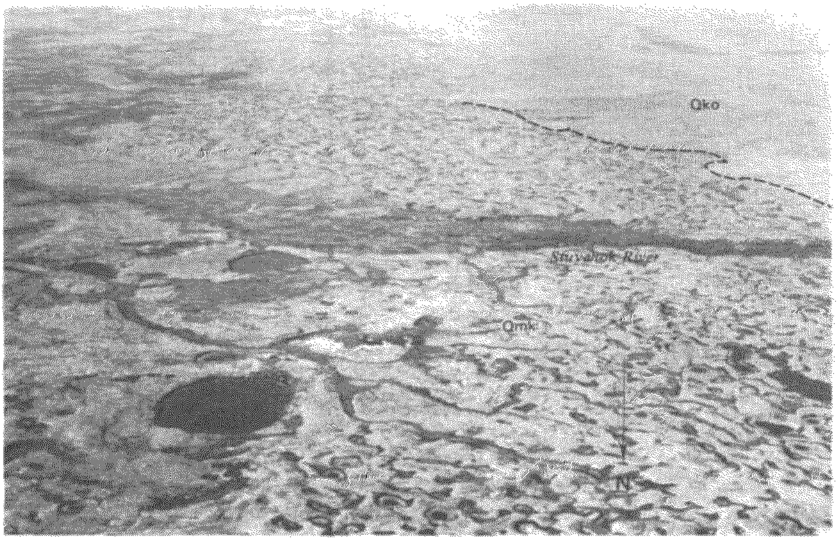

FIGURE 5.—Moraine (Qmk) and outwash (Qko) of the Kukaklek Stade of the Mak Hill Glaciation along Stuyahok River about 1 mile west of map border. View south. Photographed in September 1968.

of this modification is a subdued landscape in which the glacial origin of the topographic features can still be seen, but the original form has been altered more than the associated morainal deposits.

Ground morainal deposits.—Several small patches of low rolling knobs typical of ground moraine are present along the Stuyahok River. These are the only unmodified remnants of the formerly extensive ground moraine deposits of the Mak Hill Glaciation. The unsorted nature of these deposits indicates that they were formed under the moving glacier.

Outwash deposits.— Glacial outwash in the form of a gently sloping plain graded to end moraine of the Kukaklek Stade has been mapped north of the Stuyahok River, along the border of the quadrangle. Mass wasting and deposition of loess have obliterated the anastomosing stream pattern and pitted surface that are typical of younger outwash plains. Post-Kukaklek drainage, primarily from the Brooks Lake glacier front, was superimposed on the outwash commonly at an angle to the original slope. The plain consists largely of gravel with some silt and sand; most of the finer materials were carried beyond the border of the quadrangle.

Abandoned-channel deposits.—Deposits in broad channels incised into ground moraine and originating from a lobe of the end moraine are mapped as abandoned-channel deposits. The bottom of each channel is usually flat where it does not contain a modern stream, and where streams are present, they are obviously underfit. The channels range in width from about 200 feet to three-quarters of a mile. The deposits in them are mainly stratified gravel and sand with lenses of silt; cut-and-fill structures are common. The top layer is generally silt that probably was carried into the channel from the loess mantle after the channel was abandoned.

Age.—The Kukaklek Stade is not dated radiometrically, but an indication of the age can be obtained indirectly from other areas. It is clearly older than the late (classical) Wisconsin deposits of the Brooks Lake Glaciation. Furthermore, the Kukaklek deposits are mantled with a thin layer of silt or loess (not mapped) which is younger than the moraine. A similar loess deposit covering similarly modified moraines in the Kotzebue Sound area has been dated as >34,000–38,000 years by McCulloch, Taylor, and Rubin (1965), who considered it to represent a Wisconsin glacial event and clearly younger than the Sangamon. Karlstrom (1960, 1964) also presented evidence from the Kenai Peninsula for a glacial advance prior to the (classical) Wisconsin but still within the Wisconsin Glaciation. We believe the Kukaklek State is part of this same early Wisconsin Glaciation.

BROOKS LAKE GLACIATION

The Brooks Lake Glaciation (Muller, 1953) was named after Brooks Lake, 30 miles south of the Iliamna quadrangle in the Katmai National Monument. Muller recorded two stades of the Brooks Lake Glaciation at the type area, and several additional push moraines indicate minor fluctuations. In the Iliamna quadrangle four main stades can be distinguished, each containing one or more recessional moraines. Some of the recessional moraines may be minor push moraines, indicating some forward movement during the general recession of the glacier fronts.

The stades are named, from oldest to youngest, Kvichak, Iliamna, Newhalen, and Iliuk. Deposits from these stades cover approximately 40 percent of the land area of the quadrangle, and are mostly concentrated in the western part. Much of the remaining area below 1,200 feet was covered by ice during this glaciation, but identifiable drift is not present or is in exposures too small to map. Areas containing scattered erratics are not shown, but their presence, along with glacially scoured grooves in bedrock, indicates glacial action in areas not covered by drift. For example, on the southwest flank of Augustine Volcano exotic ice-polished boulders of granitic rock and schist are found between 950 and 1,000 feet above sea level, which indicates that at least part of Cook Inlet has been filled by ice. However, it cannot be positively stated that these boulders date from the Brooks Lake Glaciation.

KVICHAK STADE

The Kvichak Stade is here named for the Kvichak River, which drains Iliamna Lake and flows southwest to Bristol Bay. A prominent end moraine of the Kvichak Stade, considered the type locality, crosses the river approximately 23 miles downstream from Iliamna Lake and 18 miles west of the quadrangle boundary (fig. 6).

This is the earliest stade of the classical Wisconsin Glaciation in the Iliamna area. The ice margins were 5–20 miles beyond those of the younger Iliamna Stade and 200–400 feet higher. The main ice lobe accumulated in the mountains northeast of the head of Iliamna Lake. Major trunk glaciers fed into this ice mass from both north and south; the main part coming down the Newhalen River valley from Lake Clark. Another large glacier came down Battle and Kukaklek Lakes and joined the Iliamna lobe near the southwest end of Iliamna Lake. Other deposits of this stade were laid down by large glaciers that lay primarily beyond the confines

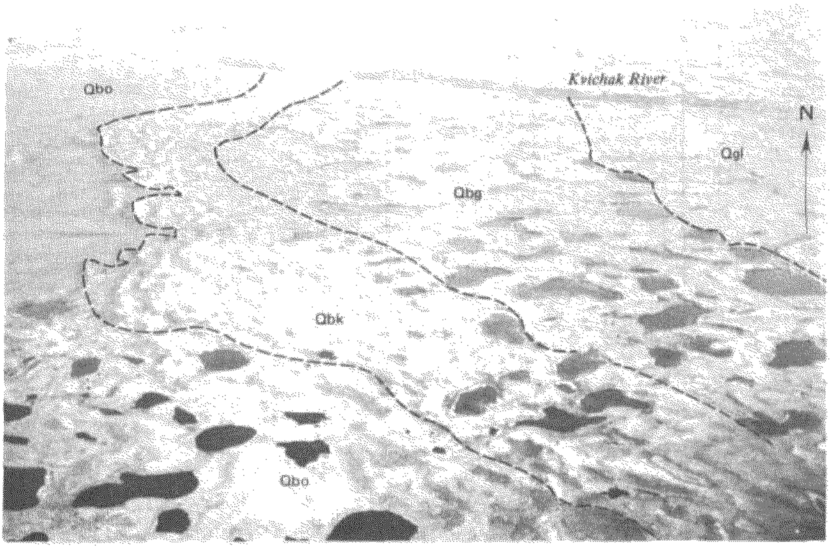

FIGURE 6.—Type locality of the Kvichak Stade, the end moraine crossing the Kvichak River about 23 miles west of Iliamna Lake looking north. Qbk, end moraine; Qbo, outwash plain; Qbg, ground moraine; Qgl, proglacial lake deposit. Photographed in September 1968.

of the quadrangle; one glacier came down Nonvianuk Lake, and minor lobes of another are found along the northern part of the mapped area.

The Kvichak Stade is represented, for the most part, by one prominent end moraine with associated ground moraine and glaciofluvial deposits, recessional moraines and (or) push-moraines having been buried by deposits of the Iliamna Stade. The head-water region of the Koktuli River, however, contains a complex system of recessional moraines; this entire area lies beyond the moraine of the Iliamna Stade and thus gives a better picture of the fluctuations that occurred during the retreat of the Kvichak ice fronts.

ILIAMNA STADE

The last major glacial advance in the area is here named the Iliamna Stade. The type locality is designated as the morainal hills 15 miles north of the outlet of Iliamna Lake, after which it is named. Till and associated glacial and glaciofluvial deposits from the Iliamna Stade cover more of the quadrangle than all the other stades combined and confine Iliamna Lake and other large lakes in this part of Alaska.

Major trunk glaciers coming from both north and south joined the one down Iliamna Lake to cover most of the area except the higher hills and mountains. The Kukaklek Lake lobe (fig. 7) joined the Iliamna glacier during at least part of the stade. The Nonvianuk Lake glacier did not coalesce with the glaciers to the north, but it did join a lobe coming from the Naknek Lake area to the south. A few of the topographically lower valleys along the north edge of the map were invaded by lobes from a major glacier just to the north. Most of the undifferentiated drift in the eastern part of the quadrangle probably is from this stade, and Cook Inlet was probably blocked also.

The Iliamna Lake glacier was approximately 125 miles long, and other glaciers were mainly 50–75 miles long. The end moraine nearly everywhere lies 20–60 miles beyond end moraine of the next stade. A complex system of recessional moraines lies behind the end moraine, indicating at least three major stillstands of the ice and possibly one minor readvance.

NEWHALEN STADE

A third stade of the Brooks Lake Glaciation was separated from the first two by a considerable time interval and was much smaller in extent. This stade is here named the Newhalen Stade after the Newhalen River where a well-exposed end moraine, considered the type locality, crosses the river about 6 miles north of Iliamna (fig. 8).

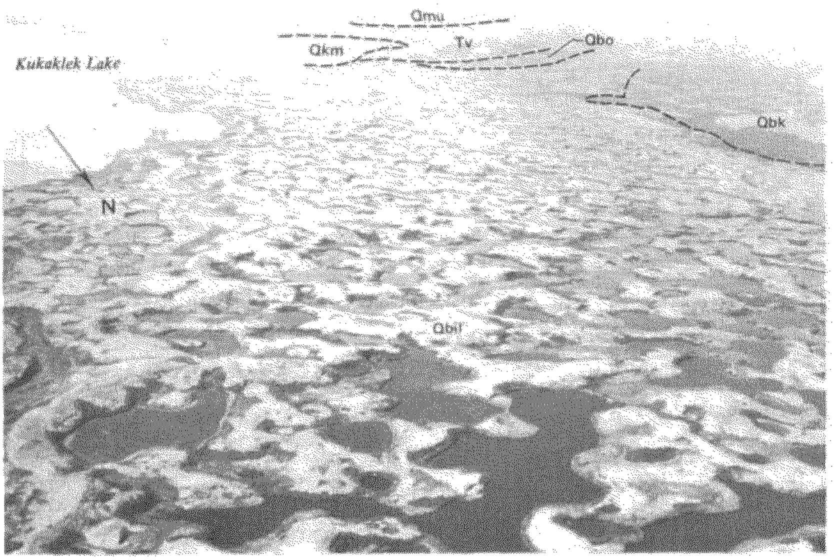

FIGURE 7.—Moraine of the Iliamna Stade along north side of Kukaklek Lake looking southwest. Qbil, moraine of Iliamna Stade; Qbk, moraine of Kvichak Stade; Qbo, kame terrace; Qkm, modified moraine of Kukaklek Stade; Qmu, drift of Mak Hill Glaciation; Tv, Tertiary volcanic rocks. Location of area shown on plate 1.

Glaciers forming the Newhalen Stade were all small alpine valley glaciers that did not coalesce except at the type locality, where glaciers from Lake Clark and Tazimina Lake joined to fill the Newhalen River valley.

End moraines were 20–60 miles back of the end moraine of the Iliamna State, and in most places no more than 20–30 miles from the source areas in the mountains. The moraines of the Newhalen Stade actually give a much better indication of source areas than do those of the large ice masses of the previous glaciations. Rock fragments in the moraines can generally be traced to specific source areas. At least three recessional moraines are associated with this stade; these are best developed along Lower Tazimina Lake in the northern part of the area and along Moraine Creek in the southern part.

ILIUK STADE

The final stade of the Brooks Lake Glaciation was named the Iliuk advance by Muller (1953, p. 2–3) after moraines at its type locality on the Iliuk Arm of Naknek Lake, about 32 miles south of the Iliamna quadrangle. According to Muller (1953, p. 3) moraines of this advance, here considered a stade, separate "upper

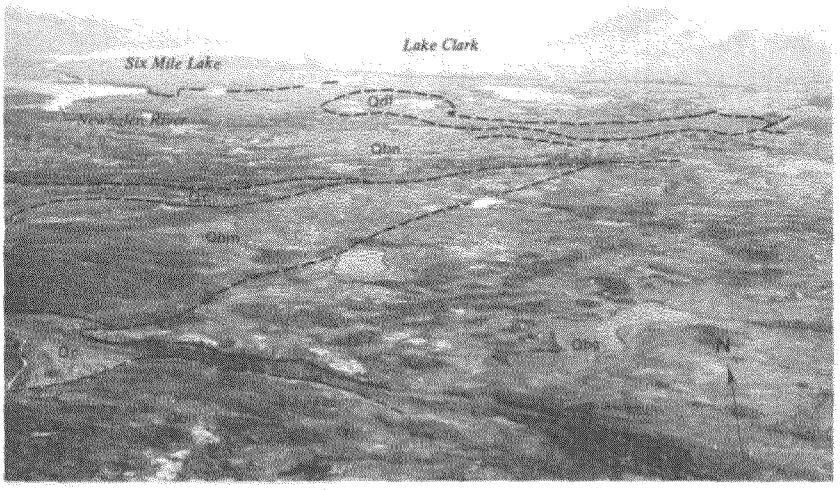

FIGURE 8.—End moraine, the type locality of the Newhalen Stade, along the Newhalen River north of Iliamna looking north. Qbn, end moraine; Qbm, modified moraine; Qdf, outwash fan; Qc, abandoned channel; Qbg, ground moraine; Qbil, moraine of the Iliamna Stade. Photographed in September 1968. Location of area shown on plate 1.

lakes or arms from the main lake in each basin * * *." Two lakes separated by a morainal dam in a single basin is a common feature in this part of Alaska, and the morainal dam is generally an end moraine of the Iliuk Stade. This feature is actually seen at only one place in the Iliamna quadrangle, between Battle Lake and Kukaklek Lake (fig. 9). However, two lakes that extend into the quadrangle, Lower Tazimina and Nonvianuk, are the lower segments of similarly divided lake basins.

End moraines of this stade generally are no more than 10–20 miles from the accumulation areas in cirques, and approximately the same distance behind end moraines of the Newhalen Stade. The glaciers were all small apline valley glaciers having their source in numerous cirques which nourished many small tributary glaciers. Many of the cirques have been little modified by subsequent Holocene glaciations. They are generally the smallest in a series of compound cirques which reflect the progressively smaller size of each of the Brooks Lake stades. Locally, as near Iron Springs and Mirror Lakes and south of Battle Lake, one recessional moraine marks a brief stillstand during the retreat of the Iliuk Stade. There may have been others that were covered by Holocene glacial deposits.

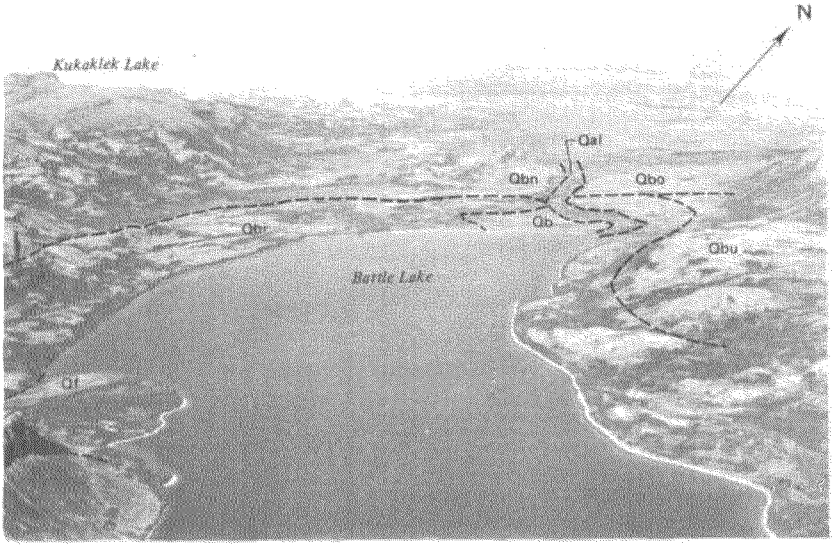

FIGURE 9.—Morainal dam formed by the Iliuk Stade between Battle and Kukaklek Lakes looking northwest. Qbi, end moraine; Qbo, outwash plain; Qf, alluvial fan; Qbn, moraine of Newhalen Stade; Qbu, drift of Brooks Lake Glaciation; Qb, beach deposit; Qal, alluvium. Photographed in September 1968. Location of area shown on plate 1.

MORAINAL DEPOSITS

Moraines of the Brooks Lake Glaciation are little modified, retaining fresh knob-and-kettle topography, but each is slightly more modified than the one of the stade that followed. Lobate end moraines marking the irregular front of the glaciers at their maximum stand for each stade can be followed for many miles. Recessional morainal fronts are less well preserved and are partially covered by glaciofluvial deposits.

Kettle ponds are for the most part undrained; a few are being filled with loess and vegetation, but most still retain the irregular shape left by the melting ice blocks. Drainage is poorly integrated, and the streams are nearly all controlled by the morainal borders. Erratics, many with ice-polished and striated faces, are common on the surface of the Brooks Lake moraines. Moraines of the two older stades contain a heterogeneous assemblage of rock types, indicating the multiple source areas of the tributary glaciers. Localized source areas of the relatively smaller Newhalen and Iliuk Stades are indicated by the fact that their moraines contain fewer different types of rock.

The amount of vegetational cover varies widely but is not a criterion for determining the age of a moraine; it is more a function of climatic zones. Some of the youngest moraines are locally heavily forested, whereas the oldest moraines at comparable elevations may be only tundra covered.

GROUND MORAINE DEPOSITS

Ground moraine was deposited by each stade of the Brooks Lake Glaciation, but for convenience the deposits are not mapped separately. Generally the deposits lie immediately behind well-defined end moraines in the western part of the quadrangle; in the mountainous eastern part they are abundant but are not associated with end moraines. Most of the deposits in the eastern part cannot be identified with a particular stade, although most probably date from either the Kvichak or Iliamna Stades.

The deposits are mainly of unsorted till in the form of irregularly shaped, nondirectional mounds and knobs a few feet to a few tens of feet high. Most were probably formed under the moving ice, although some were undoubtedly formed by ablation during the melting of the glaciers.

TERRACED AND MODIFIED MORAINAL DEPOSITS

Morainal deposits herein mapped as terraced and modified moraines were original deposited as ground moraine, but were subsequently modified by streams emerging from glaciers of succeeding advances. In many places the deposits lie adjacent to outwash plains or hanging deltas and are partly covered by these deposits. The original character of the ground moraine was additionally altered by a thin layer of loess derived from braided stream channels in front of the glaciers. In many places runoff streams issuing from glaciers have created the terraces.

OUTWASH AND PITTED OUTWASH DEPOSITS

Glaciofluvial deposits in the form of outwash plains, pitted outwash, and kame terraces cover many square miles of the Iliamna quadrangle. The largest plains border the fronts of the Kvichak and Iliamna end moraines, where they are commonly $1\frac{1}{2}$–2 miles wide and many miles long. These plains are of great extent because of a protracted stillstand of the major glaciers.

The outwash plains extend beyond the end moraines, and slope approximately 25–50 feet per mile. Braided channel scars are common, but all are shallow, indicating that streams shifted rapidly across the plain. Pitted outwash borders the front of moraines where the deposits covered blocks of ice that subsequently melted. Numerous pits in the Kaskanak Creek area are over 50 feet deep and resemble sinks in karst topography. Just north of the west end of Iliamna Lake the outwash deposit is 65 feet thick and composed mainly of alternating layers of silt and

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gravel with lenses of cobbles. Involute structures are present, similar to those described by Miller and Dobrovolny (1959, p. 65–67) in the Anchorage area.

A well-developed kame terrace deposit extends along the south side of the Kvichak moraine west from Kukaklek Lake. Between Kukaklek and Reindeer Lakes the terrace is 300–800 feet wide and is confined by hills just to the south (fig. 10). The former ice margin is now represented by a scarp 25–50 feet high along the inner edge of the kame terrace. Other outwash deposits mantle and partly obscure ground moraine of both the Mak Hill and Brooks Lake Glaciations.

HANGING DELTA AND OUTWASH FAN DEPOSITS

Hanging delta and outwash fan deposits are similar in origin. Both were formed by streams entering glacial Lake Iliamna when it was near its maximum level, and by streams coming down steep canyons and debouching onto low-gradient plans. The deposits are typically deltaic and consist of stratified layers of cobbles, pebbles, sand, silt, and glacial lake clay. The layers dip toward the old lake bed at angles of 10°–15°; channel scars and cross-bedding are common, as are ripple marks in some of the sand and silt layers.

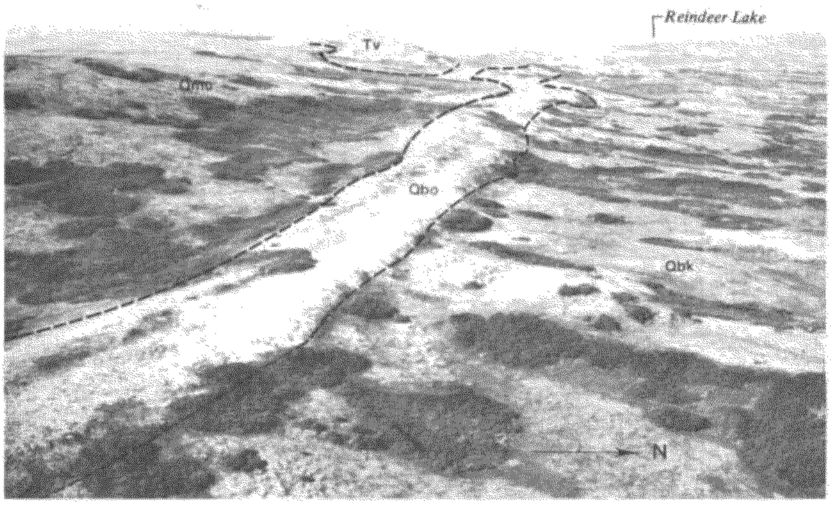

FIGURE 10.—Kame terrace along south side of Kvichak moraine between Kukaklek and Reindeer Lakes. Glacier was along right side of the kame terrace. Qbo, kame terrace; Qbk, moraine; Qmu, drift of Kukaklek Stade; Tv, Tertiary volcanic rocks. Photographed in September 1968. Location of area shown on plate 1.

Most of these deltaic deposits are associated with outwash of the Kvichak and Iliamna Stades and are at the mouths of abandoned channels entering glacial Lake Iliamna.

The hanging deltas and fans are roughly of two sizes and shapes, as well as at two levels. Members of the higher of the two sets are also the larger, being 2–4 miles long and nearly as wide at the outer edge; they are roughly triangular and contain a greater abundance of coarse fragments. The lower edge of this set is generally above an elevation of 200 feet. Deltas of the lower set are commonly narrow and linear, up to 4 miles long and rarely more than one-quarter to half a mile wide; this set is at 100–150 feet above sea level, and much of the material is sand and silt (fig. 11).

ABANDONED-CHANNEL DEPOSITS

Many broad channels incised into moraines of the Brooks Lake Glaciation contain stratified and graded deposits of silt, sand, and gravel. Most of these channels now are occupied by underfit streams; locally no streams are present. The channels originate along both the outer and inner edges of end and lateral moraines and probably were active only during the period of maximum

FIGURE 11.—Hanging delta near Ole Creek southwest of Iliamna Lake looking northeast. This is one of the low deltas and is composed of well-drained sand and gravel with a covering of mature spruce forest. Qdf, hanging delta; Qgl, proglacial lake bed; Qbk, moraine of the Kvichak Stade; Qbm, modified moraine; Qc, abandoned-channel deposits. Photographed in September 1968. Location of area shown on plate 1.

melting. Many of these channels end in hanging delta and outwash fan deposits. The positions of the abandoned channels suggest numerous occurrences of stream piracy as well as shifting of channels in response to changing base level. The lower part of the Newhalen River, for example, has shifted about 10 miles to the east through a series of channels, some of which are abandoned and others of which contain underfit streams. At one time, when the lake was at its highest level, the mouth of the Newhalen River was about 5–6 miles northeast of its present location. Thus, the river has shifted both east and west in response to changing conditions.

PROGLACIAL LAKE DEPOSITS

Iliamna Lake is a moraine-dammed lake in a preexisting structural depression that was originally an extension of Bristol Bay. The glacial lake was confined by the end moraine of the Kvichak Stade of the Brooks Lake Glaciation 23 miles southwest of the present lake outlet. Now the lake is confined by the end moraine of the Iliamna Stade 2–3 miles west of the lake. Most of the area between the end moraines of the two stades is covered by proglacial lake deposits; these deposits are in part covered by glaciofluvial deposits of the Iliamna Stade.

The proglacial lake deposits have a very characteristic topographic expression (fig. 12). The surface is nearly flat and covered by myriad small ponds that are remnants of larger ponds. Much of the area between ponds is covered by quaking bogs, in which the water level is at or near the surface. The only firm ground is adjacent to streams that cross the deposits.

The deposits consist almost entirely of silt- and clay-size particles smaller than 0.050 mm. Locally, sand and pebbles are present where ground moraine of the Kvichak Stade is near the surface or where glaciofluvial deposits of the Iliamna Stade partly overlie the proglacial lake bed. The silt and clay is light gray to tan, locally laminated, and of variable thickness; 20–50 feet is suggested by the depth of stream entrenchment into the deposit. Exposures are very poor except locally along the Kvichak River. The upper part of the deposit is rich in organic material. Lenses of interstitial ice are present, and relict permafrost features are common.

The proglacial lake deposit is probably similar in many respects to the Bootlegger Cove Clay in the Anchorage vicinity (Miller and Dobrovolny, 1959) and formed under similar conditions.

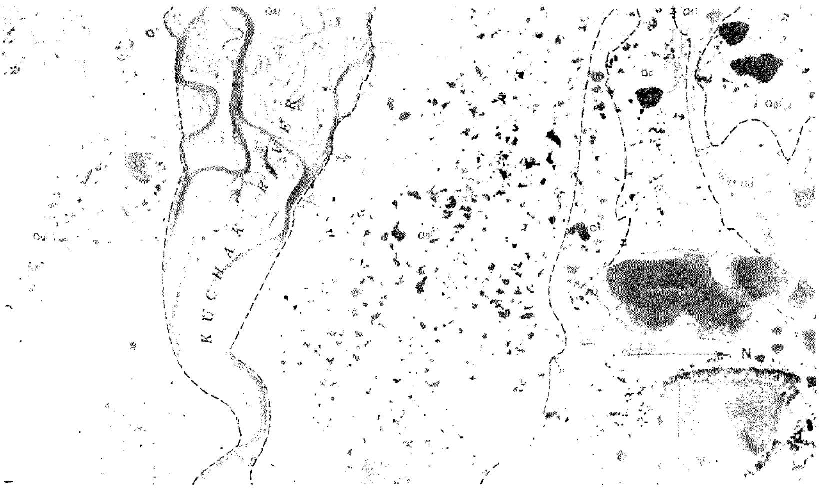

FIGURE 12.—Proglacial lake deposit at west end of Iliamna Lake. Qgl, proglacial lake deposits; Qrl, lake terrace; Qd, sand dunes; Qc, abandoned-channel deposits in former outlet for Iliamna Lake; Qal, alluvium. Photograph by U.S. Air Force, 1955. Location of area shown on plate 1.

HOLOCENE GLACIAL DEPOSITS

ALASKAN GLACIATION

Glacial deposits of Holocene age are almost entirely restricted to the higher parts of the coastal mountains along Cook Inlet, where high precipitation, coupled with altitudinal lowering of temperatures, produced minor glaciers in post-altithermal time. Karlstrom (1957) called this period of glacial advance the Alaskan Glaciation and subdivided it into the Tustumena and Tunnel Stades, each with several minor fluctuations.

The mountainous area bordering the west side of Cook Inlet contains a glacial sequence that corresponds very closely to the multiple advances that Karlstrom (1960, 1964) described on the east side of Cook Inlet. Elsewhere in the quadrangle, the Alaskan Glaciation is marked only by one or two sets of end moraines that are mapped as undifferentiated deposits of the Alaskan Glaciation. Most of the undifferentiated deposits probably belong the the Tustumena Stade, which was older and more extensive than the Tunnel Stade.

A slight shift in the local climatic conditions within the quadrangle during the time of the Alaskan Glaciation may be indicated by the position and extent of the deposits. In the southern part of the quadrangle end moraines of the Tustumena are farther from the cirques than they are in the northern part. The opposite is true of moraines of the Tunnel Stade.

The deposits in the Iliamna quadrangle have not been dated radiometrically but are probably coeval with dated deposits (Karlstrom, 1964, pl. 7) on the east side of Cook Inlet, where the Alaskan Glaciation began about 4,500–4,800 years ago and continued with minor interruptions until about 200 years ago. The modern glaciers are all remnants of the Alaskan Glaciation.

TUSTUMENA STADE

Morainal deposits of the Tustumena Stade are found at many localities in the mountains bordering Cook Inlet. The glaciers were all small and of the alpine-valley type. They extended no more than 2½ miles from cirque headwalls in the southern part of the quadrangle and generally less than 1½ miles from headwalls in the northern part. Exceptions to this occur in the glaciers coming from Iliamna Volcano just beyond the northeast corner of the quadrangle; these are major glaciers, some of which are still over 15 miles long.

At most localities arcuate moraines of two advances can be mapped, the younger about a third to half a mile behind the older outer moraine. At a few spots there is a faint suggestion of a third advance between the two prominent end moraines, but in all likelihood these are small recessional moraines. Karlstrom (1957, 1960, 1964), however, mapped three advances on the east side of Cook Inlet.

TUNNEL STADE

A relatively minor resurgence of glaciers that started about 1,200 years ago in the Cook Inlet region was termed the "Tunnel Stade" by Karlstrom (1957), who mapped two distinct pulses on the east side of Cook Inlet. Two sets of end moraines are present also at many localities in the Iliamna quadrangle, where they lie ½–1½ miles from cirque headwalls, except near Iliamna Volcano.

During the Tunnel Stade the snowline was no more than a few hundred feet lower than the present 3,500-foot snowline, and many cirques close to this line have only minor threshold dams of moraine; the snowline was depressed to about 2,500 feet during the Tustumena Stade.

MORAINE AND OUTWASH DEPOSITS

There is little difference in appearance between moraines of the two stades of the Alaskan Glaciation; both are fresh and unmodified. The end moraine is sharp, knob-and-kettle topography is fresh, and streams are not integrated. A few of the deposits have brush cover, but most are above timberline. Rock fragments in moraines were locally derived from cirque headwalls, and most still retain their angular shape. Ablation moraine is still forming on top of the modern glaciers coming down from Iliamna Volcano; the surface below about 3,000 feet is an almost solid cover of rock, sand, and silt.

Outwash from the Alaskan Glaciation is mapped at only two localities, along West Glacier and Middle Glacier Creeks. Small patches are present elsewhere but are too small to show. Where mapped, the constituent fragments are mainly volcanic rock from Iliamna Volcano mixed with sand and silt. These areas of outwash are still growing by the addition of material contributed by existing glaciers in the valleys.

MODERN GLACIERS

All the modern glaciers are in the northeastern part of the quadrangle, north of Iliamna Bay, and within 15 miles of the coastline. This is an area of high precipitation (fig. 3) where almost constant cloud cover during the summer prevents melting of the ice. Four large glaciers are nourished by the snowcap on Iliamna Volcano (10,016 ft), and extend into the quadrangle north of Chinitna Bay; two of these terminate at elevations of less than 1,000 feet. Although ablation moraine covering the surface of the ice prevents rapid melting, they are shrinking slowly.

Most of the modern glaciers are in northwest-facing cirques; 34 can be mapped (fig. 3). The largest is just over a mile long, but most are a quarter to half a mile long. The firn line is now between 3,500 and 4,300 feet. The elevation at which ablation terminates the cirque glaciers varies directly with the distance from the coastline; at 5 miles inland it is about 2,200 feet, at 10 miles it is 2,800 feet, and this increases to about 3,300 feet at 15 miles. Thus, the ablation zone rises about 100 feet per mile. The firn line rises at about 50 feet per mile or half the rate of rise of the ablation zone.

MASS MOVEMENT AND FROST ACTION DEPOSITS

LANDSLIDES

Landslides are one of the major products of mass movement in the quadrangle. Glacially oversteepened valley walls, highly fractured bedrock, and earthquake tremors all help cause large masses of material to move suddenly in response to gravity. Most of the landslides are in the area of heavy rainfall in the coastal mountains, and water saturation undoubtedly helps to reduce friction in fractured bedrock as well as unconsolidated surficial materials. The buoyant effect of the water also aids in moving the mass of debris after it has been set in motion.

The largest landslides are in Jurassic sedimentary rock on Iniskin Peninsula, where millions of cubic yards were involved in slides as much as 2 miles long. Slides are also abundant in Tertiary volcanic rocks, particularly near Squirrel Point on the south side of Iliamna Lake and around Groundhog Mountain west of Nondalton. Landslides are not common or large in granitic or metamorphic rock terrane, except at one locality about 2½ miles east of Moose Lake where landslides in granitic rocks from mountains on opposite sides of the valley have partly blocked the valley. These slides are not the same age; the one from the north appears much younger and has partly overridden the slide coming down from the south side of the valley.

The debris in most landslides is composed of large angular blocks of bedrock and minor amounts of surficial material that were caught up in the movement. Nearly all slides are now stabilized with vegetation; even where vegetation is absent there is at least a lichen covering on most blocks. Spruce forest covers the slide at Right Arm of Iniskin Bay. The only recent landslide, about 25 years old, is in granitic rock just west of Lonesome Bay at the head of Iliamna Lake (Carl Williams, oral commun., 1967), and both the scar and slide appear fresh. Some of the landslides date from the Pleistocene or perhaps even earlier, as they are partly covered by Pleistocene glacial deposits.

The earthquake of March 27, 1964, did not cause any landslides in the Iliamna quadrangle. Minor amounts of talus and a few fragments of bedrock were jarred loose, but no major sliding occurred in spite of 12–18 inches of uplift along the west side of Cook Inlet (Plafker, 1965). A slide, however, did occur at Tuxedni Bay, about 20 miles northeast of the quadrangle.

TALUS AND RUBBLE

Talus and rubble are mapped as one unit and considered together in this report. Both are formed primarily by frost action on bedrock, the main difference being that talus is moved downslope by gravity whereas rubble remains where it formed.

Sheets, fans, and cones of angular frost-riven rock fragments accumulate on steep slopes in the mountainous areas of the quadrangle, but only the larger deposits can be shown at the mapping scale. The most extensive areas are underlain by granitic rock. Augustine Volcano is covered by loose talus blocks, but their origin is related to volcanism rather than to frost action, and these deposits are not mapped with surficial units.

Most of the talus postdates the Kvichak and Iliamna Stades of the Brooks Lake Glaciation, as during that time ice covered most of the mountainous areas of the quadrangle to a depth of 1,300–1,500 feet, and much of the talus formed prior to these stades was incorporated in the glacial deposits. Some probably was formed shortly after these stades. Much talus is being formed at the present time. These rocks are lichen free, and rockfalls can be seen and heard nearly every day while there is diurnal freezing and thawing.

Rubble covers many of the nearly flat to gently rounded hilltops and upland surfaces that stand above the general limit of the Brooks Lake Glaciation. The areas of frost-riven rubble are much less extensive than areas covered by talus, in part because of the restricted extent of topographic features conducive to the formation of rubble and the slower rate of formation.

The main areas of rubble are west of the coastal mountains and include Roadhouse Mountain, the areas just south of Lower Tazimina Lake and around triangulation station Kashanak, part of Sharp Mountain, and areas around Battle, Iron Springs, and Pilot Lakes. The main areas of rubble are underlain by many different rock types but are most common on granitic and Tertiary volcanic terranes.

The fact that boulders in most rubble fields are lichen covered indicates they are not actively forming at the present time. However, within each deposit there are a few upturned and lichen-free boulders which show there is still a minor amount of frost churning. Minor patterned ground and segregated rings are present, but most of the boulders in a deposit are fairly constant in size, those in granitic rock being larger than those in volcanic rock.

SOLIFLUCTION

Solifluction lobes are conspicuous features on the tundra-covered slopes in the northwestern part of the quadrangle, particularly above the limit of the Brooks Lake Glaciation. The slow downward creep of the regolith is aided by alternate freezing and thawing, sparse vegetation cover, the abundance of fine-grained debris, including loess, and sufficient moisture. Solifluction proceeds slowly now, and the more conspicuous lobes probably date from a colder climate during the Brooks Lake Glaciation.

The topography in the northwestern part of the quadrangle is characteristic of that produced by solifluction; the hill slopes are convex, and tors have formed at their crest. The tors, remnants of nearly flat-lying lava flows, are the only bedrock exposed at many localities. On convex hill slopes the rate of creep is greatest on the upper part of the hill, and the lobes pile up on midslope. Locally, north of Sharp Mountain, where glaciers have oversteepened the valley, creep is fastest on the lower slope, and cliffs are formed near the base of the hill.

The process of solifluction is most common where the regolith contains a considerable amount of fine material, such as loess-mantled hills and drift of the Mak Hill Glaciation. The large areas affected on the northwest-facing slopes between Knutson Bay and Lower Tazimina Lake were probably covered with a thin layer of drift from the Mak Hill Glaciation. The material being transported downslope undergoes a minor amount of sorting, and crude polygonal ground is formed—fine materials concentrated in the center and coarse fragments around the outside. A few terraces are found with rock fragments along their steep faces on north-facing slopes northeast of triangulation station Kaskanak.

ROCK GLACIERS

Rock glaciers are rare in the Iliamna quadrangle, as the area is near the southern limit at which they form and are preserved; however, they are common and active farther north in the Alaska Range (Wahrhaftig and Cox, 1959; Holmes and Foster, 1968). The five small rock glaciers mapped in the quadrangle are inactive or nearly so, and probably have been since the Tunnel Stade of the Alaskan Glaciation. The rocks are mainly lichen covered, except for part of the steep forward face, and there appears to be little or no new material being added to the surface of the glaciers.

These rock glaciers have many of the characteristics described by Wahrhaftig and Cox (1959) in the central Alaska Range. The most striking features are the crescentic ridges and furrows bowed downslope (fig. 13). Deep conical thaw pits and longitudinal ridges are common on their surfaces, which are covered by large boulders resting on finer debris. The faces of the rock glaciers are steep and moderately high; the one on Middle Mountain is about 125 feet high, but most are somewhat lower. Normal downslope movement keeps some individual boulders in the face lichen free, but there does not seem to be any general movement of the entire mass.

All the rock glaciers mapped have a distinct wall of debris facing unslope, with a pit formed between the wall of debris and the cirque headwall, and there is no identifiable moraine of the Tunnel Stade. All the deposits are small, half a mile or less in length, and the cirques producing them are small. This suggests

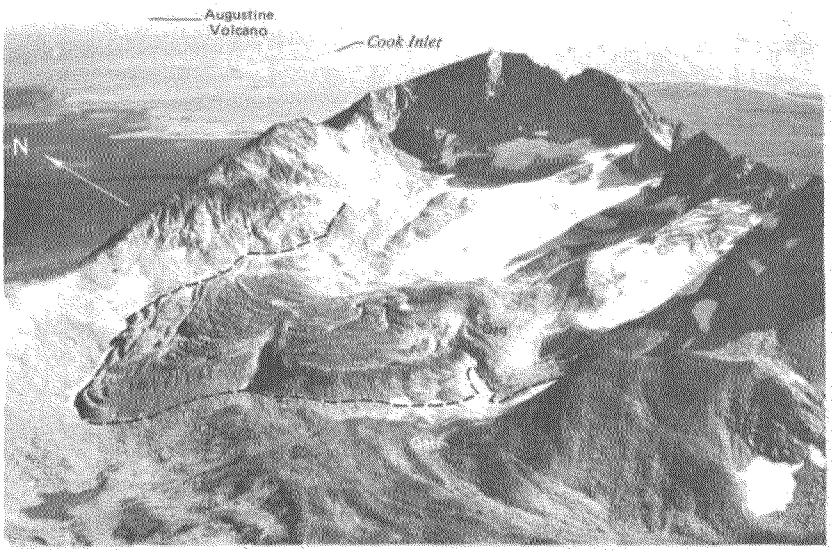

FIGURE 13.—Rock glacier on Middle Mountain looking east. The glacier is short and step-sided and is not moving at present. Concentric ridges and thaw pits are prominent near the terminus. Qrg, rock glacier; Qott, moraine of Tustumena Stade. Photographed in September 1968. Location of area shown on plate 1.

that locally there may not have been enough ice during the Tunnel Stade to form a true glacier, and rock glaciers formed instead. The time of formation would thus be 200–400 years ago. The pit between the cirque headwall and the upslope-facing wall of debris actually may mark the position of a small ice mass that formed at that time but did not move forward.

PATTERNED GROUND

Well-defined patterned ground is present, but not common, in the quadrangle. Most features are relicts of former periods of glaciation and are only on a few of the higher mountains or where special climatic conditions exist. Nearly all have been mentioned in the discussion of the different surficial units, and only a brief résumé will be made here.

Relict high- and low-center polygons are fairly common locally in the northwestern part of the quadrangle, but frost-crack polygons are apparently the only ones now forming. Hummocks and tussocks are present in many of the swampy areas at all elevations. Some segregation of coarse and fine debris is noted in solifluction lobes and rubble ridges on hilltops, but this is mainly a relict feature. Circular pits with low mounds of fine debris around the outer margin may be former pingos, but none are active in the area now.

ALLUVIAL DEPOSITS

TERRACE DEPOSITS

Crudely stratified terrace deposits, mainly of gravel and sand with level or gently sloping upper surfaces, are found at many localities in the Iliamna quadrangle. These deposits, all the result of action by water, formed in three types of environment—fluvial, lacustrine, and marine. Some of the deposits display aspects of more than one of these three but are grouped under the primary or main contributing one.

Terrace deposits attest to the presence of water at an elevation above that which it now occupies. This change in elevation may result from many factors, from local uplift that affects a small part of a drainage basin to major changes in sea level in response to glacial advance and retreat.

Terraces are rarely simple, except possibly in the headwater areas of streams, where only one level may be present; lower stream valleys and the shores of lakes and seas generally have a complex series that represent several periods of alluviation or change of base level.

Terraces formed by fluvial or glaciofluvial action are on all streams in the quadrangle, except the small steep ones cut mainly in bedrock. Many are too small to show at the scale of the map, and some have been included with flood-plain alluvium. The hanging delta and outwash fan deposits are forms of terrace but are mapped separately.

The best examples of multiple stream terraces are along the Koktuli, Kvichak, Alagnak, Nonvianuk, and Newhalen Rivers. These are all in heavily glaciated areas where vast amounts of debris were flushed rapidly down the valleys during periods of deglaciation after the Kvichak and Iliamna Stades; this debris caused streams to aggrade their channels and form broad flood plains. Subsequently the decreased load accompanied by changes of sea and lake level during the latter part of the Brooks Lake Glaciation caused these streams to form multiple terraces along much of their courses.

The deposits are locally more than 100 feet thick and consist mainly of poorly stratified, well-rounded pebbles and cobbles with interbeds and lenses of sand and silt. There is a general decrease in clast size away from morainal fronts, as well as away from headwater source areas.

Along the Kvichak, Alagnak, and Nonvianuk Rivers the terraces are generally narrow, paired, and have few levels, and the streams are deeply incised—features that indicate rapid downcutting. The Koktuli River, on the other hand, has a broad terrace area and many minor levels, none of which seem to be paired, and abandoned channel and meander scars are common—features that indicate slow adjustment to new base levels.

Martin and Katz (1912, p. 87–93 and fig. 3) discussed terrace gravel at elevations up to 2,000 feet in the Tazimina Lake-Lake Clark areas. Most of the area shown in their figure 3 is outside the Iliamna quadrangle and was not investigated, but that part south of Tazimina Lake was checked. Most of this gravel is in glacial outwash and kame terrace deposits along the valley wall; that in the pass areas is a remnant of drift from glaciation that preceded the Brooks Lake. Tributary streams may have been dammed by main valley glaciers north of Tazimina Lake, as discussed by Martin and Katz, but no evidence of this was found south of the lake.

FLOOD-PLAIN ALLUVIUM

Deposits formed by the action of running water primarily during the Holocene are here mapped as alluvium. The two main types are flood-plain alluvium and alluvial fans and cones. The former is deposited by streams of any size; the latter are formed mostly by steep-gradient ephemeral streams. For the purpose of this report, low terraces, up to 5 feet above stream level, are included with the alluvium.

Flood-plain alluvial deposits are largest and most abundant in the western part of the quadrangle, where large masses of unconsolidated glacial debris are being reworked and moved downstream. Many of the streams, such as the Koktuli, Stuyahok, and Alagnak Rivers and Kaskanak, Moraine, and Belinda Creeks, are obviously underfit. They have broad flood plains with low gradients and contain many oxbow lakes, cut-off meanders, meander scrolls, sloughs, and back swamps. They are flowing in glacial stream channels, but most of the mapped alluvial deposits in these valleys probably are Holocene. Older deposits are mapped with the terrace deposits.

Most of the streams entering Iliamna Lake are deeply entrenched and are degrading their channels in response to progressive lowering of the lake level. The lower courses of the Iliamna and Pile Rivers are exceptions; they are about at grade and periodically flood across the width of the valleys because the lower 5–6 miles of their courses is across and old lake bed formed by a higher stand of water in Iliamna Lake, and the streams are graded to a level only slightly above that of the present lake. Normally the level of Iliamna Lake rises about 5 feet during the heavy rainfall season from June through August; this change in level brings the Iliamna and Pile Rivers about to grade, and there is little movement of alluvium along their lower courses.

Sand and gravel.—Interstratified sand and gravel make up the bulk of the alluvial materials throughout the quadrangle. Gravel, for the purpose of this discussion, is considered to include all water-worn rock fragments up to about 10 inches (254 mm) in diameter; fragments larger than 10 inches are considered boulders.

Most streams originating in the coastal mountains, particularly ones flowing eastward into Cook Inlet, have a high percentage of boulders and only minor amounts of sand and gravel.

Silt.—Silt and fine sand make up a major part of the alluvium in the western part of the quadrangle, an area containing extensive loess deposits and the oldest glacial drift. Most of the streams are underfit and cannot transport large rock fragments. Many follow the outer edges of outwash plains in fine-grained material, and so they receive very little coarse material. No size analyses were made, but the grain size is probably in the fine sand range. Generally the particle size of alluvium at any given point is larger than that of the bulk of the material being eroded at that point. Each time the stream recrosses its flood plain, or adds new material, the finer particles are moved farthest downstream, leaving coarse material behind. In cross section the flood plains are nearly level, but the longitudinal profiles vary considerably, from steep in the mountains to low in the western part.

The silt is poorly to well stratified; it is mainly brown but includes some gray and black material. The black silt contains variable amounts of organic material, and some of the quaking bogs on the proglacial lake sediments are almost entirely peat. The gray silt is probably a glacial lake deposit. These valley-fill sediments are poorly drained, nearly flat, and coextensive with abundant swamps and muskeg.

ALLUVIAL FANS AND CONES

Alluvial fans and cones are more abundant in the mountainous parts of the quadrangle, where steep-gradient streams debouch onto low-gradient flood plains. Large fans are present near Sixmile Lake, Roadhouse Mountain, and Chekok, Knutson, East Glacier, and Moraine Creeks. Cones are particularly abundant in the coastal mountains, but only a few of the larger ones are mapped.

The materials are generally coarser and more angular than flood-plain deposits, they are rarely submerged, and the fans and cones have distinctly convex cross sections. Both are composed mainly of locally derived rock fragments, but also include minor amounts of glacial drift. Most are covered with forest or brush and are gullied, so that they are now being dissected, rather than accumulating. None of the deposits are dated radiometrically, but the main period of formation probably corresponds to the Alaskan Glaciation.

BEACH DEPOSITS

LAKE TERRACE AND BEACH RIDGE DEPOSITS

A series of prominent lacustrine terraces are present along much of Iliamna Lake. They are more common in the thick surficial materials around the western end but are also present in some of the valleys at the head of the lake, notably the Iliamna and Pile River valleys. The shores of Kukaklek, Nonvianuk, and Sixmile Lakes also exhibit at least one major terrace.

The multiple terraces on Iliamna Lake are particularly striking along the north and west sides, where four major levels can be mapped (pl. 1 and fig. 14) at about 40, 80, 100, and 130 feet above the present lake level (47 ft). In addition, minor terraces were formed at about 55 and 115 feet above present lake level. All elevations are probably correct to ± 3 feet. The 40- and 80-foot terraces are the best preserved and most continuous. Their width is generally 1,000–3,000 feet but locally is as much as 5,000 feet.

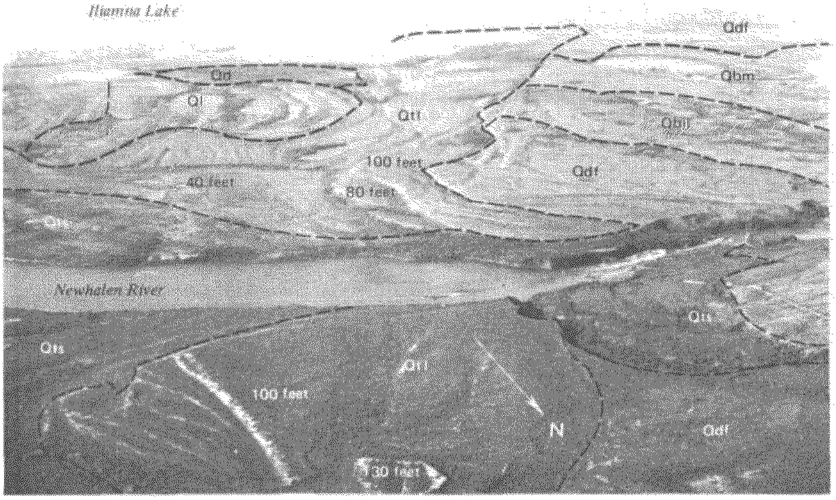

FIGURE 14.—Lake terrace and beach ridge deposits along north side of Iliamna Lake, west of Iliamna airport, looking southwest. Qtl, lake terrace and beach ridge deposits, showing 40, 80, 100 and 130-foot levels; Qts, stream terrace; Qdf, outwash fan; Qbm, modified moraine; Ql, lacustrine deposits; Qbil, moraine of Iliamna Stade. Photographed in September 1968. Location of area shown on plate 1.

The upper surface of each slopes lakeward at about 5° and is terminated by a wave-cut scarp behind another terrace at a lower level. The action of water and wind has greatly altered the terrace surfaces in many localities; this is both constructional, with the formation of sand dunes and beach ridges, and destructional, through downcutting of stream valleys.

The highest stand of water in glacial Lake Iliamna was about 150 feet above present lake level (fig. 15). This level was apparently maintained only briefly, as terraces and beach ridges were not formed. However, the strandline can be identified easily on aerial photographs and locally on the ground where there is only a light vegetation cover. Surficial materials below the high waterline are modified, and they show a distinct light-gray tone on aerial photographs owing to a thin coating of stratified sand and gravel.

The time of the highest water level is unknown, as no material for radiocarbon analysis has been found. However, stratigraphic considerations suggest a post-Iliamna age, and in all probability the high-water level was during the Holocene warming dated by McCulloch (1966) at about 8,300–11,000 years ago in the Chukchi Sea area. Radiocarbon dates have been determined for Iliamna

Lake terraces below the high waterline. The oldest sample is dated at 8,250 ± 350 years B.P. (before present) (Detterman, Reed, and Rubin, 1965); this is from the 80-foot terrace level and is presumably younger than the highest stand of water, although this cannot be proved.

Pits excavated into lake terraces revealed many similarities as well as dissimilarities in the exposed sections. Some sections show soil profiles that were apparently interrupted by a lake transgression with deposition after which a new soil profile developed. The soil horizon terminology used here is the standard used by pedologists (Leopold and others, 1964, fig. 4–2, p. 117).

Section into top of 80-foot terrace level, 7.8 miles N. 25° W. of the outlet of Iliamna Lake

	Inches
Fine sand, dark-yellowish-orange (10*YR*6/6, Munsell system); mostly quartz, some frosted grains; A_0 soil horizon	12
Fine sand and silt, dark-yellowish-brown (10*YR*4/2); considerable organic material; A_1 horizon	1
Silt and fine sand, grayish-orange (10*YR*7/4); A_2 horizon	24
Pea gravel, well-rounded	8
Unsorted, unweathered till	--
Total	45

The terrace at the sample site is largely barren of vegetation now and probably has been since formation. A few spruce grow locally. Soil horizons are poorly developed, and frosted sand grains indicate active wind erosion. The lake probably did not transgress this terrace after its formation.

A section into the 55-foot terrace in the forested moderate rainfall zone at the head of the lake shows a thicker and better developed soil profile and a second transgression of the lake across the terrace.

Section 0.5 mile northeast of Pile Bay village

	Inches
Moss and root zone; A_0 horizon	2
Volcanic ash, white; 1912 Katmai eruption	½
Loam, moderate brown (5*YR*3/4); organic material; A_1 horizon	2½
Loam, pale-yellowish-brown (10*YR*6/2); A_2 horizon	2
Sand, medium to coarse; lake transgression	1
Silt and loam, moderate brown; A_1 horizon	7
Silt, yellowish-gray (5*YR*8/1); organic material; probably glacial lake silt	2
Till, unsorted and unweathered	--
Total	17

A more complete section through the surficial materials can be seen in a lake bluff at the northwest corner of Iliamna Lake, 12 miles north of the outlet.

	Feet
Loam, silty, moderate to light-brownish; A_1 and A_2 horizons	12
Sand, coarse, yellowish-brown; beach deposit	25
Gravel, pebbles and cobbles; poorly stratified to unsorted glacial outwash	8
Till, unsorted	60
Total	105

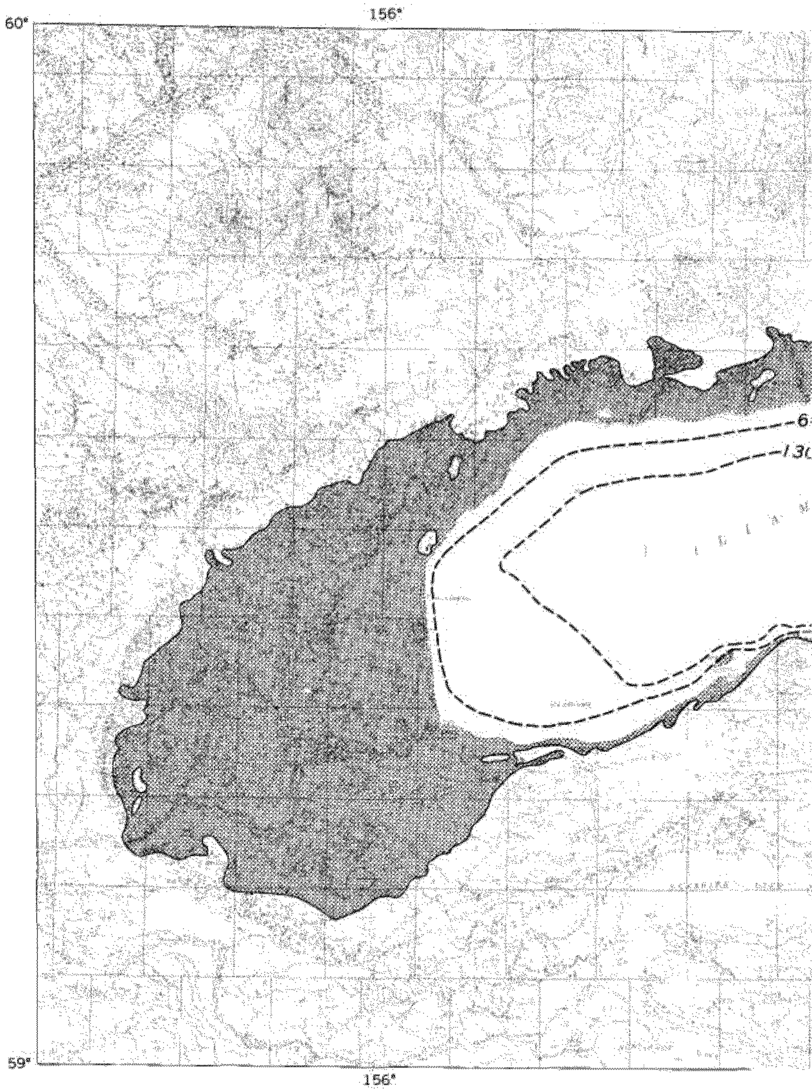

FIGURE 15.—Bathymetry of Iliamna Lake and area covered at maximum stand of glacial Lake Iliamna. Contours, in feet, modified from bathymetry by Fisheries Research Institute, University of Washington. Shaded land area covered by water of glacial lake during melting following the Iliamna Stade.

Tilting of Iliamna Lake, probably as a result of isostatic adjustment since deglaciation, is suggested by the terrace levels and southward migration of the outlet (fig. 12). This tilting, which

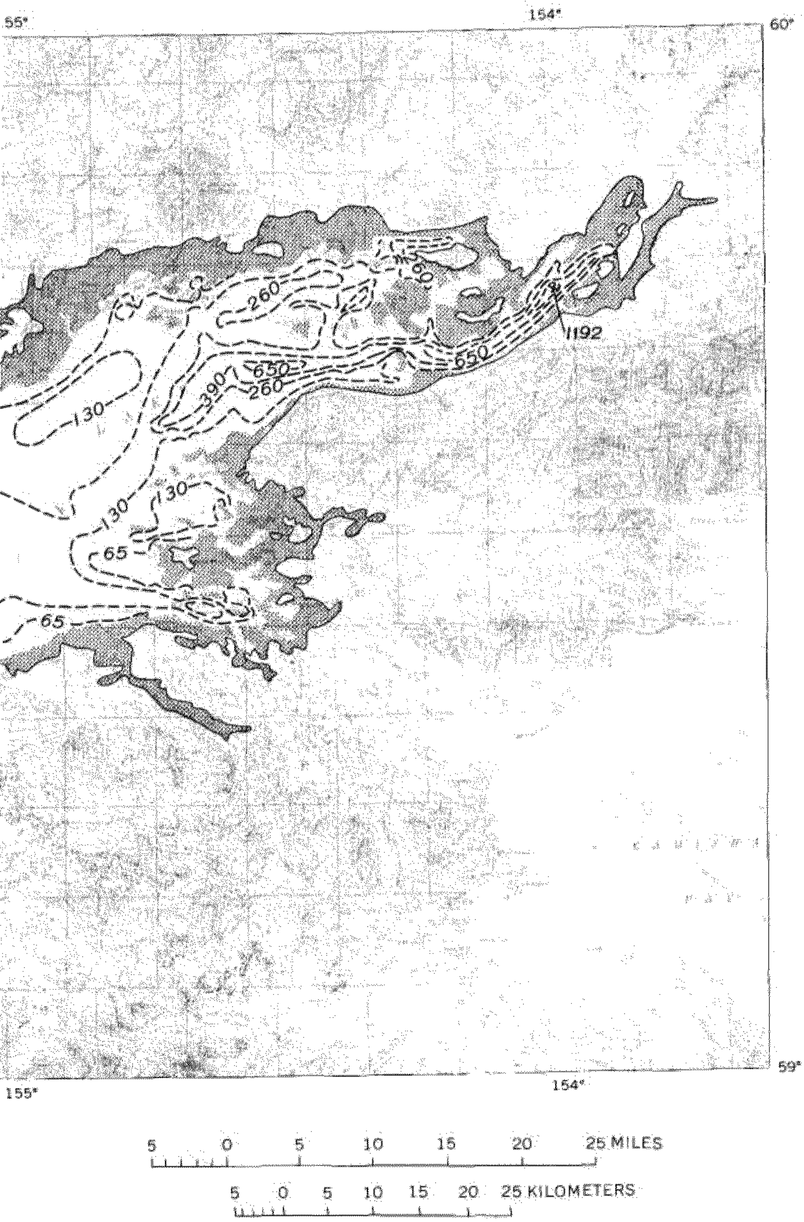

FIGURE 15.—Continued.

cannot be proved with the information at hand, would be caused by a slight uplift of the north shore.

MARINE TERRACE AND BEACH RIDGE DEPOSITS

The west shore of Cook Inlet is rising, partly in response to tectonic activity (Plafker, 1965; Waller, 1966; Detterman, 1968) and possibly in part owing to isostatic adjustments following deglaciation. Evidence for this uplift can be seen in many places in the form of beach deposits far above high-tide line and wave-cut bedrock platforms along Kamishak Bay covered by marine surficial deposits. Karlstrom (1964) presented evidence for a fresh-water lake, Lake Cook, in the upper Cook Inlet area. As much as 1,000 feet deep, it was formed by an ice dam during the maximum stand of the Knik Glaciation and was entirely drained by 7050 B.C. ± 750 years. Radiocarbon dates from the top of a 50-foot bedrock platform indicate the Kamishak Bay deposits are less than 3,000 years old and are therefore probably marine as Shepard (1960, 1964) and Curray (1961) presented evidence that sea level during the last 20,000 years was lower than at present.

Remnants of two generations of wave-cut bedrock terraces or platforms are particularly abundant along the shores of Kamishak Bay at levels approximately 50 and 90 feet above high-tide line (fig. 16). The higher level is more prominent and generally wider

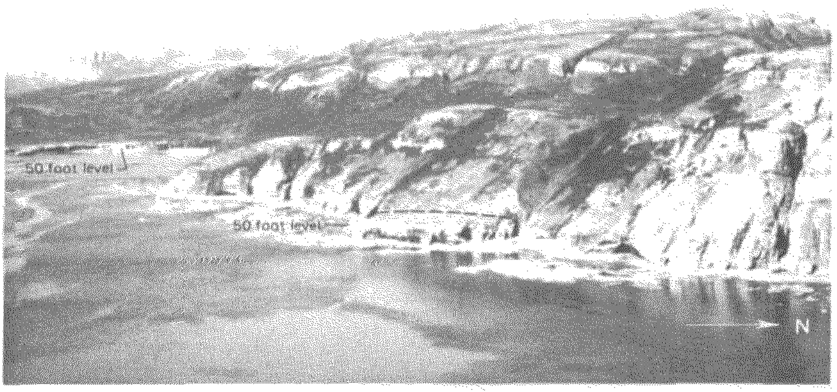

FIGURE 16.—Marine terraces cut into bedrock at Amakdedulia Cove, Kamishak Bay, looking southwest. The 50-foot level is well developed and covered by beach deposits; a new level is forming at wave base. Photographed in September 1968. Location of area shown on plate 1.

than the lower, and probably represents a longer stillstand of sea level. Beach deposits, some with well-defined soil horizons, overlie most of the platforms. A section overlying the 50-foot platform, measured along the east side of a small stream 9 miles west of the mouth of the Douglas River, follows:

	Feet	*Inches*
Modern root zone; A_0 horizon		4
Volcanic ash, white; 1912 Katmai eruption		4
Sand, pebbles, lenticular and reworked peat layers only partly decomposed; secondary, disturbed A_0 horizon		21
Loam, dark-yellowish-brown (10*YR*4/2) with abundant organic material (2620 B.P.); A_1 horizon		17
Sand, pale-yellowish-orange (10*YR*8/6); A_2 horizon	6	0
Pebbles, cobbles, and sand	8	0
Total	17	10

The following incomplete section of material on top of the 90-foot platform 2¾ miles northeast of Chenik Lake indicates a possible fluctuation in sea level or changing conditions of deposition.

	Feet
Cobbles, pebbles and sand, all well rounded; cobbles flattened and form beach shingle	2
Silt and clay with some fine sand, moderate yellowish-brown (10*YR*5/4), crossbedded	10
Cobbles and pebbles similar to above	1½
Silt and clay, similar to above but not crossbedded	8
Slumped, mainly fine material to top of bedrock	10
Total	30½

Elsewhere along the shore of Kamishak Bay and northward, unconsolidated to slightly consolidated deposits of sand and gravel are present at the two main levels. One deposit, graded to the 50-foot level, is about 1 mile inland from the beach at Amakdedori, and one graded to the 90-foot level is on the peninsula jutting out from the south side of Bruin Bay. Both levels are on Augustine Island, where several intermediate levels that are not well represented elsewhere are also present.

Low beach ridges, some with beach berms, are present at the head of Oil Bay and Dry Bay. The ridges are progressively higher inland, but all are below the 50-foot terrace level. They were not investigated for radiocarbon material but are probably fairly young, even though they support mature spruce forest on the higher ridges.

A radiocarbon date of 2,620 ± 250 years was obtained from organic material derived from plants that grew on a deposit overlying the 50-foot bedrock platform 9 miles west of the mouth of the Douglas River. This organic debris overlies 14 feet of sand

and gravel deposited on the bedrock, and so the date may be considerably younger than the date of formation of the platform. However, using that date and disregarding any sea-level change in the same interval, the minimum rate of uplift in this area is between 1 and 2 feet per century.

MODERN BEACH DEPOSITS

Modern beach deposits along Iliamna and other large lakes are composed primarily of well-rounded pebbles and cobbles derived from glacial deposits bordering the lakes. Angular fragments broken from bedrock cliffs are locally a minor part of the deposits, but sand beaches are not common except at the west end of Iliamna Lake and at the head of Pile Bay. Other small sand beaches are at the west end of Kakhonak, Meadow, and Kukaklek Lakes, and at the head of Moose Lake.

In most places Iliamna Lake beaches are less than 25–30 feet wide, but some have two or three well-defined beach berms that extend uninterrupted for several miles. Beaches on the north side are generally wider than those on the south side.

The shore of Cook Inlet is bordered mainly by rocky cliffs with few beach deposits, except for angular blocks of bedrock, though there are large beaches of gravel and sand at Chinitna and Oil Bays, Ursus Cove, Amakdedori, McNeil Cove, and at the mouth of the Douglas River. Augustine Island has some beaches formed mainly of pumice and sand. The lack of extensive beaches along this part of Cook Inlet is probably a reflection of the continued recent uplift.

LACUSTRINE DEPOSITS

The term "lacustrine deposit" is used here in a restricted sense. Broadly speaking, it refers to all deposits formed in or by a lake; as used here, all materials reworked into terraces, or beach ridges, and all swamp deposits are excluded.

The main area of deposition was in glacial Lake Iliamna below the highest terrace level. Smaller deposits are along Kukaklek, Kakhonak, and Nonvianuk Lakes. They are present elsewhere, but the exposures are too small to show at the scale of the map.

Most of the deposits were probably formed in a periglacial environment and consist mainly of glacially transported material, though some fluvial deposits were undoubtedly incorporated, particularly near the present lake levels and near the mouths of the larger streams.

The components of the lacustrine deposits are mainly silt and fine sand (0.05–0.25 mm) and a few interbeds of coarse sand and gravel. They are poorly drained, owing to the small particle size, and tend to be swampy. Organic material, much of it reworked, is common in layers and lenticular masses.

A partial section of a lacustrine deposit was excavated at an archeological site 0.2 mile west of the Nels Hedland house at Pedro Bay. The area is mapped as swamp deposit, but a low terrace only about 25 feet wide was cut in the side of Pedro Mountain and is covered with lacustrine deposits. The section is as follows:

	Inches
Modern root zone	2
Volcanic ash, white; 1912 Katmai eruption	¾
Organic layer, partly decomposed plant fragments	¾
Volcanic ash, gray	1
Loam, black, highly organic (1,340 B.P.)	7½
Sand, fine to coarse, poorly stratified, leached	1¾
Ash, gray	¾
Organic layer	¼
Silt, gray	2
Organic layer	¼
Ash	½
Organic layer	½
Soil, weathered gray	2+
Total	20+

Exposed in a pit near Chekok Bay, at about the same elevation, was 18 inches of gray glacial lake silt and clay underlying 15 inches of fine sand and overlying coarse gravel.

ESTUARINE DEPOSITS

Two types of estuarine deposits form in the bays of Cook Inlet—silt and salt marsh deposits. They are considered together because they both form by tidal action. The main difference between the two is that estuarine silt lies below high-tide level, and salt marsh lies generally above but may be periodically flooded by extreme high tides.

All the fiordlike bays along Cook Inlet, as well as Kamishak Bay, contain extensive deposits of estuarine silt that are exposed at low tide. The heads of most of these bays, except for stream channels, are completely dry on a minus tide, and the deposit at Kamishak Bay is exposed for 5–6 miles offshore.

The surface of the silt slopes gently toward the center of the bays or toward meandering stream channels that cross them. Sections through the upper parts of the deposits are occasionally exposed in some of the stream channels after a storm. Where exposed, the deposits show considerable small-scale crossbedding, with thin layers of sand and small pebbles. Large pebbles and cobbles are incorporated into the deposits near shore.

The estuarine silt is mainly an accumulation of rock flour carried into the bays by streams that head in melting glaciers. The process is still going on in Chinitna Bay and to a lesser extent in Kamishak Bay. Elsewhere, accretion is from rock flour carried down Cook Inlet by tidal action. Most of the material is in the clay and silt range (0.005–0.05 mm). The clays are medium-bluish gray (5*B*5/1) and extremely plastic and sticky when wet. For the most part they are compacted enough to support a man's weight, but locally small circular areas 5–15 feet in diameter are "quick," probably the result of seepages from springs.

Salt-marsh deposits bordering the upper parts of most bays are identical in composition with the estuarine silt, except that they contain vegetation layers and peat. The deposits are above water most of the time, but new silt may be added when extreme high tides are accompanied by storms.

EOLIAN DEPOSITS

LOESS

A thin mantle of loess covers much of the upland surfaces that are underlain by till of the Kukaklek Stade of the Mak Hill Glaciation. The deposit is only a few feet thick at most places and was not mapped. The major source was probably silt from outwash plains of the Brooks Lake Glaciation. Some loess is being deposited today from the flood plains of the larger streams during periods of dry, windy weather.

SAND DUNES

An extensive area of dunes overlies some of the high terraces and beach ridges at the west end of Iliamna Lake. These terraces have only a sparse cover of vegetation and are fully exposed to the sweep of the southeast storms. Smaller areas of dunes occur at intervals along the north side of the lake; they are all formed on old lake terraces. Two small dune areas are present on the north and west sides of Kukaklek Lake. Along Cook Inlet there are only two small areas of sand dunes, one at the southwest tip of Augustine Island and another at the mouth of the Douglas River. Elsewhere along Cook Inlet, the beach materials are coarse.

The dunes are only partly stabilized by a sparse vegetation cover, and blowouts are common; these expose the internal structure of crossbedded layering, aeolian ripple marks, and lag gravel. Organic material is common in many of the blowouts; two samples from a pit at the west end of Iliamna Lake (pl. 1, loc. C 1–4) were dated. The upper horizon at 11 inches below the surface was dated as 200 years old and the one at 54 inches as 400 years (Detterman, Reed, and Rubin, 1965). The sample at 54 inches overlies a thin bed of white volcanic ash which may be equivalent to one reported from a dune on Turnagain Arm by Miller and Dobrovolny (1959, p. 80).

The material exposed in the pit at the west end of Iliamna Lake is mainly fine clean quartz sand in which most of the grains are somewhat frosted. About 1 foot below the surface, just beneath the upper organic layer, the section contains 20–25 percent silt mixed with the sand, but the wind removed all silt from the upper few inches of the active layer. The upper organic layer contains many partly burned wood and plant fragments, which may indicate that the dunes had been stabilized by a vegetation cover that was destroyed by a fire about 200 years ago.

VOLCANIC ASH

Thin layers of wind-transported volcanic ash are admixed with the surficial deposits in all parts of the quadrangle. The thickest layer is a white ash found throughout the area at the base of the root zone. It was deposited by the 1912 eruption of Mount Katmai and Novarupta at the head of the Valley of Ten Thousand Smokes, 50 miles south of the quadrangle. This layer ranges in thickness from about a quarter of an inch in the northwestern part of the quadrangle to as much as 4 inches in the southeastern part.

The most recent ash deposit resulted from the 1963 eruption of Augustine Volcano. This ash is confined to the mountainous areas along the west side of Cook Inlet and did not extend more than 15 miles inland. No attempt was made to correlate the ash layers except for the 1912 eruption. Two radiocarbon dates (W–1483 and W–2148, table 1) are closely associated with ash beds and give an approximate date of deposition. There are at least eight historically active volcanoes within 50 miles of the quadrangle that could have supplied the ash (Coats, 1950). Augustine is the only one within the mapped area; it has been active five times since 1760.

SWAMP DEPOSITS

Swamps are common throughout much of the quadrangle, especially in closed depressions in glaciated areas and along lakes, ponds, and streams in the lowlands. The proglacial lake deposit at the west and of Iliamna Lake is a vast area of swamps and quaking bogs. Fine-grained sediments near the terminal edges of outwash plains are commonly swampy, as is much of the lake-bed sediment bordering Iliamna Lake.

A swamp deposit, or muskeg as it is commonly called in Alaska, is mainly a dark-brown organic accumulation of woody and peaty material mixed with silt and fine sand. Sedge and sphagnum peat are both present. Alaskan muskeg was classified into three groups by Dachnowski-Stokes (1941, p. 3–5): slope muskeg, raised muskeg, and flat or valley muskeg. This classification is based on topographic, structural, and developmental differences.

Slope muskeg has sloping surfaces and forms on gently undulating ground near sea level. Many of the swampy areas bordering Iliamna Lake are of this type. Most of the swamps in the quadrangle would be classified as flat or valley muskeg, which has a flat to slightly concave surface. Several small swamps near the head of Pile Bay have slightly convex surfaces and may be raised muskeg.

The thickness of the swamp deposits was not determined, but 38 inches of sphagnum and sedge peat was noted at one spot near Chekok Bay where the lakeshore had cut into a deposit. A drainage ditch just west of the Iliamna River, along the Pile Bay-Iliamna Bay road, exposes about 2 feet of similar material. In both places and elsewhere in the quadrangle, the actual depth of swamp deposits is probably much greater than that observed.

ORGANIC DEPOSITS

Peat and finely divided organic material are found in most of the surficial materials. The organic content of most of the moraines is low, but the kettles, ponds, and swales contain considerable peat. Large peat bogs now in the process of formation cover much of the proglacial lake deposits and lacustrine deposits. Quaking bogs are common around the west end of Iliamna Lake, as well as near Pedro Bay and Pile Bay. The surface of these organic deposits is commonly marked by sedge tussocks, earth hummocks, and marsh-type vegetation. Fine, well-sorted, well-stratified, and poorly consolidated silt is mixed with the organic material. Much of this silt is black to dark brown.

RADIOCARBON AGE DATING

Eight samples containing organic material were obtained and analyzed for their radiocarbon content in an effort to date some of the surficial deposits. Some of the samples represent in place accumulations of organic material, and others are of material that grew elsewhere and was washed into the places where samples were collected. The locations of all samples are shown on plate 1, and the analyses are presented in table 1.

Samples C–1 through C–4, from the 80-foot terrace at the west end of Iliamna Lake, give a minimum age for the Iliamna Stade

TABLE 1.—*Radiocarbon analyses of organic material from Iliamna quadrangle Alaska*

[Analyses by Meyer Rubin, U.S. Geol. Survey]

Locality No.	Laboratory No.	Sample description	Locality description	Depth below surface (inches)	Age (years B.P.)
C-1	W-1482	Wood and plant stems.	80-ft terrace level, Iliamna Lake; eolian sand deposit.	11	200±200
2	1483	Plant fragments and seed pods.	80-ft terrace level; eolian sand deposit.	54	400±200
3	1481	Organic material	80ft terrace level; glacial lake beach deposit.	72–76	1,980±250
4	1479	...do	...do	132	8,520±350
5	2147	Twigs, grass, and seed pods.	55-ft terrace level; glacial lake deposit.	10	5,520±250
6	2148	Black humus and peat layer.	55-ft terrace. Swamp deposits.	5–13	1,340±250
7	2123	Organic material and peat in brown soil horizon.	Beach deposit overlying 50-ft wave-cut bedrock platform.	30	2,620±250
8	2288	Organic material in beach sand.	Raised beach deposit, Augustine Island.	30	Modern

of the Brooks Lake Glaciation. The stade is probably considerably older, as the material is from a level that is approximately 70 feet lower than the maximum stand of the lake. The youngest date (200±200 B.P.) was from burned wood and may indicate that this part of the quadrangle was more heavily forested a few hundred years ago (fig. 2). These samples have been described before (Detterman, Reed, and Rubin, 1965).

Samples C–5 and C–6 are from the 55-foot terrace along the north side of Iliamna Lake. Sample C–5, from near Chekok Bay, is from material washed onto the beach during formation of this terrace level and probably gives a good date for the formation of the terrace. Sample C–6 is in place material associated with an archeological site near Pedro Bay and is undoubtedly much younger than the terrace.

The two samples from Cook Inlet, C–7 from Kamishak Bay and C–8 from Augustine Island, give a maximum rate of uplift along the west side of Cook Inlet. Peat formed in place overlying 14 feet of sand and gravel on the 50-foot bedrock platform at Kamishak Bay would indicate a maximum rate of 1–2 feet of uplift per century. The modern age of the material from Augustine Island would tend to confirm this rapid rate of uplift. The Augustine Island carbonized debris was collected 7 feet above high-tide line and had been an integral part of a beach deposit. About 12–13 inches of the uplift resulted from the 1964 earthquake (Detterman, 1968).

GEOLOGIC HISTORY

The geologic history of the surficial materials in the Iliamna quadrangle is the record of events that occurred during the late Pleistocene and Holocene. Any deposits that were formed prior to the Wisconsin Glaciation are so completely covered or altered as to be unrecognizable, though pre-Wisconsin glaciers must have covered a large part of the area.

At the beginning of Pleistocene time, this part of the Alaska Peninsula appeared much different than it does today. Iliamna Lake was undoubtedly part of Bristol Bay, and Big Mountain was probably an island. The lake is as much as 1,192 feet deep and certainly was not formed entirely by glacial scouring. The coastal mountains were probably much different also. The fiordlike bays along Cook Inlet were probably narrow river valleys.

The oldest recognizable glacial deposits in the quadrangle resulted from an early Wisconsin advance that has not been dated radiometrically but is correlated with the Mak Hill Glaciation in the Naknek Lake area (Muller, 1953) and the Knik Glaciation (Karlstrom, 1960, and 1964) on the east side of Cook Inlet. Valley glaciers from the mountains coalesced to form a piedmont lobe that covered much of the quadrangle to a considerable depth and probably continued across the lower part of Cook Inlet as an ice dam. Deposits of this glaciation are found only along the western border of the quadrangle and mainly at altitudes over 1,000 feet. These deposits are believed to be more than 35,000 years old because of their morphologic similarity to dated deposits.

The oldest glacial deposits were considerably eroded and otherwise modified before the late (classical) Wisconsin Glaciation, represented by four stades of the Brooks Lake Glaciation. Valley glaciers coalesced to form a major lobe in the Iliamna Lake area during the Kvichak Stade. Ice probably covered much of the quadrangle and terminated about 20 miles west of Iliamna Lake; moraines of this stade enclosed Iliamna Lake basin and other large lake basins in the area. The eastern limit of the ice is unknown, but ice may have dammed Cook Inlet. Several protracted stillstands of the glaciers are represented by large recessional moraines in some of the mountain valleys. Streams cut into many of the deposits, reworking and modifying the glacial debris.

During the Iliamna Stade, the last major glacial advance in the area, ice from many valley glaciers again coalesced to form a major lobe in Iliamna Lake; this terminated a few miles west of the present lake outlet and is largely responsible for the present configuration of the lake. The Kukaklek Lake lobe did not join the main ice mass but did form the Kukaklek Lake basin. Nonvianuk Lake was also formed at this time by another major lobe. Three to four recessional moraines marking major stillstands of the ice are seen in many places. Outwash deposits were mixed with the proglacial lake-bed deposits at the west end of the lake. During the subsequent interstade the glaciers melted back into the mountain valleys and may have disappeared almost entirely. The melting of this large mass of ice probably filled the lake basin to its highest strandline, about 150 feet above the present lake level, but rapid downcutting quickly lowered this level.

The last two stades of the Brooks Lake Glaciation were minor advances, mainly of small alpine valley glaciers. The glacier coming down Sixmile Lake did coalesce briefly with the one in Tazimina Lake valley to form a major ice front just north of the modern village of Iliamna. Glaciers during the Iliuk Stade did not reach the mountain front, but moraines created secondary basins in previously formed lakes. Upper Tazimina, Nonvianuk, and Battle Lakes were formed in this manner.

The glaciers of the Iliuk Stade melted in response to the ameliorating climate at the beginning of the Hypsithermal, and the Brooks Lake Glaciation came to an end. The radiocarbon date of 5,520±250 years for the beach deposit on the 55-foot terrace along Iliamna Lake probably represents the age of the high stand of the lake during the Hypsithermal.

About 4,500 years ago the climate deteriorated, and the glaciers readvanced (Karlstrom, 1964). The Tustumena Stade of the Alaskan Glaciation was a minor event in this quadrangle; most of the glaciers advanced only a mile or two from the cirque headwalls in the coastal mountains. Two to three pulsations of the Tustumena glaciers are recorded in most places. The only large glaciers at this time were around Iliamna Volcano. A few of these extended into the northeastern corner of the quadrangle.

The modern glaciers are remnants of the Tunnel Stade, which began about 1,000 years ago (Karlstrom, 1964). This was a minor advance that was confined to the higher mountain cirques and did not extend, except locally, more than half a mile beyond the headwalls. The Tunnel Stade ended about 200 years ago. Since then the glacier fronts have retreated to their present positions. The large glaciers radiating from Iliamna Volcano are almost completely covered by ablation moraine, and a forest cover is starting to grow on the terminal moraines, indicating no recent advance of these glaciers.

CONSTRUCTION MATERIALS

The following discussion is given mainly to indicate the types and location of construction materials that are available in the quadrangle. The primary objective of this study was not oriented toward engineering studies, so that none of these materials were tested for suitability in construction, except for some chemical analyses of limestone that could be used in making cement (Detterman, 1969).

SAND AND GRAVEL

Deposits of sand and gravel are abundant throughout the area west of the coastal mountains. A few deposits can be found in recent alluvium along the larger streams in the mountains, mainly the Iliamna, McNeil, and Paint Rivers. Beach deposits at Ursus Cove and Amakdedori could also furnish an ample supply for local use.

Abundant suitable material is present around Iliamna Lake in beach ridge and terrace deposits and in the numerous outwash plains, pitted outwash, hanging deltas, outwash fans, and kame terrace deposits throughout the entire western part of the quadrangle. Some of the beach deposits also contain a good supply of clean sand without gravel.

The glaciofluvial outwash deposits are somewhat graded with sand and pebbles near their outer margins. Coarser fractions could be obtained from near the morainal contacts.

CRUSHED AGGREGATE

Most of the bedrock in the coastal mountains could be used as a source of crushed aggregate. The mountains are mainly granitic rocks that are fresh and unaltered. Early Jurassic volcanic rock is available along the coast between Iniskin Bay and Bruin Bay. Triassic limestone and greenstone is present at Iliamna and Bruin Bays and north of Meadow Lake.

Iniskin Peninsula and the area bordering the shore of Kamishak Bay is underlain by sedimentary rock that for the most part would not make good crushed aggregate. Most of the western part of the quadrangle is underlain by Tertiary volcanic rocks. Basalt and andesite flows probably would make acceptable aggregate, but most of the rocks are tuffs and breccias that disintegrate readily.

The coarse fractions of the terrace and outwash deposits would also be suitable for crushed aggregate. Most of the larger rocks in these deposits are the more resistant types in the mountains, as the less resistant varieties were pulverized by moving glaciers.

LIGHTWEIGHT AGGREGATE

Pumice deposits on Augustine Island could be a valuable source of lightweight aggregate to be used in making cement blocks and other cement products for building construction. The deposits were mined briefly for that purpose between 1946 and 1949. There are many areas of nearly pure pumice on the island that could be mined. Most of the rock is already in small fragments, under 2 inches, and would require little additional crushing. Moxham (1951) briefly investigated some of the deposits.

Any mining operation on Augustine Island would need to use the lagoon at the southwest side of the island; owing to recent uplift, this would have to be dredged before it could be used.

LIMESTONE

Late Triassic limestone that could be used for the manufacture of cement is available at Iliamna Bay and Bruin Bay. Analyses of representative limestone samples are given in table 2. The limestone at both places is at sea level and readily accessible.

Another large area of limestone is about 1 mile north of Meadow Lake. Samples of this rock were not analyzed, but in hand specimen it appears to be of better grade than the rocks at either Iliamna or Bruin Bays. In addition, two small areas of limestone are present along the north shore of Iliamna Lake between Knutson Bay and Millits Point. The chemical properties of the rock there are unknown.

CONSTRUCTION PROBLEMS

The quadrangle contains many good locations for all types of building and road construction, but some areas should be avoided. This brief discussion points out a few of the latter as a general guideline for future development.

Permafrost does not constitute a major construction hazard in the quadrangle. It is present locally (p. A15) but only in small swampy areas that would normally be avoided. Permafrost might tend to form in the fine silt deposits along the outer margin of outwash plains, in the proglacial lake deposit, in lacustrine deposits, and in the swampy areas adjoining kettle ponds on moraines. The loess overlying the oldest moraine may contain some permafrost.

Some frost heaving is to be expected in this area, as in most of Alaska. However, the climate is much milder than in the interior of the State, and frost heaving much less severe. The fine, poorly drained silts are again the most susceptible to heaving.

Landslides might be a problem in the mountainous areas along the coast. The major slides of the past are shown on plate 1.

TABLE 2.—*Analyses of selected limestone samples from Iliamna and Bruin Bays, Alaska*

[Analysts: C. O. Ingamells, M. J. Cremer, L. B. Schlocker, and B. P. Fabbi. SO_3, SrO, BaO, P_2O_5, Fe_2O_3, and total sulfur determined by X-ray fluorescence; soluble CaO determined by atomic absorption spectroscopy; all other determinations by chemical analysis]

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	TiO_2	P_2O_5
M105614	30.86	2.96	2.17	1.43	43.20	0.34	0.31	0.14	0.14	0.03
15	16.95	4.63	3.11	1.45	43.80	.64	.29	.13	.24	.04
16	14.19	3.48	2.25	2.32	42.21	.53	.11	.12	.14	.04
17	5.26	1.21	.69	1.49	50.40	.10	.06	.07	.04	.04
18	12.33	.72	1.17	2.04	47.85	.14	.00	.05	.07	.04
19	11.08	.64	1.00	2.02	48.60	.15	.00	.05	.05	.04
20	32.33	3.69	2.14	1.22	33.12	1.14	.73	.07	.15	.02
21	1.39	.49	.19	.55	54.18	.12	.12	.03	.02	.03
22	1.15	.38	.40	.61	54.40	.11	.03	.04	.03	.03
23	28.63	.59	.54	.47	38.91	.13	.00	.06	.02	.04
24	2.54	.44	.41	.85	53.17	.09	.12	.03	.03	.03
25	1.59	.39	.15	.41	54.31	.15	.07	.02	.02	.03
26	14.18	5.98	2.10	1.74	40.91	.32	1.52	.04	.17	.04

Sample	SO_3	Total sulfur as S	SrO	BaO	H_2O	Ignition loss	Total	Soluble CaO	Soluble CO_2
M105614	1.25	0.04	0.04	0.01	0.12	16.57	99.45	39.9	16.57
15	.18	.07	.07	.02	.05	27.41	98.46	35.6	27.41
16	.13	.06	.06	.00	.08	34.42	100.00	41.6	33.40
17	.13	.06	.06	.00	.05	40.50	100.05	50.5	40.02
18	.10	.09	.09	.00	.07	35.43	100.03	45.3	34.90
19	.07	.09	.09	.00	.04	35.67	99.46	45.8	35.77
20	1.15	.07	.07	.06	.08	24.52	100.41	31.3	24.28
21	.13	.05	.05	.00	.01	42.74	100.04	53.2	42.55
22	.10	.05	.05	.00	.02	42.87	100.20	54.9	42.67
23	.25	.04	.04	.00	.03	20.91	99.59	38.3	30.14
24	.13	.04	.04	.00	.04	42.04	99.92	53.1	41.98
25	.10	.04	.04	.00	.04	42.71	99.99	54.6	42.66
26	.70	.05	.05	.02	.07	31.63	99.40	41.4	31.16

Glacial sour has oversteepened many of the mountainsides, making them susceptible to sliding. In addition, the coastal areas have heavy rainfall that keeps the rocks and debris saturated most of the time, and increases the danger of sliding. The rocks in the mountains are locally highly fractured, and roads should not be constructed across such areas. The road between Pile Bay and Iliamna Bay is an example. Between Summit Lake and Williamsport the road is constructed along a steep mountainside in fractured intrusive rock, and slides are numerous.

Earthquakes are common in this part of Alaska, and while no major destruction resulted here from the 1964 earthquake, they should be considered in any future construction. A major landslide did occur at Tuxedni Bay, a few miles northeast of the quadrangle, as a result of that earthquake. Because the Cook Inlet coastline is rising in this part of the Alaska Peninsula, submergence of facilities should not be a problem. Also, there are no deep fiords that might generate a submarine landslide. The greatest source of difficulty in this respect is likely to be the effect of emergence on marine facilities. The bays are mostly shallow, and a poorly selected site would be rendered useless by a moderate amount of uplift.

Roads and buildings constructed on solid bedrock, or on any of the numerous glacial moraines, outwash plains, and terraces in the quadrangle should hold up well. The proglacial lake deposits should be avoided, as the water-saturated silt and clay would react similarly to the Bootlegger Cove Clay at Anchorage (Miller and Dobrovolny, 1959; Hansen, 1965). Areas bordering Iliamna Lake below the high strandline are also locally underlain by similar clay deposits. These same conditions are present around other large lakes in the quadrangles.

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